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PROCEEDINGS

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PROCEEDINGS

of the

FIRST PAN-PACIFIC SCIENTIFIC CONFERENCE

Under the Auspices of the

PAN-PACIFIC UNION

Honolulu, Hawaii

August 2 to 20, 1920

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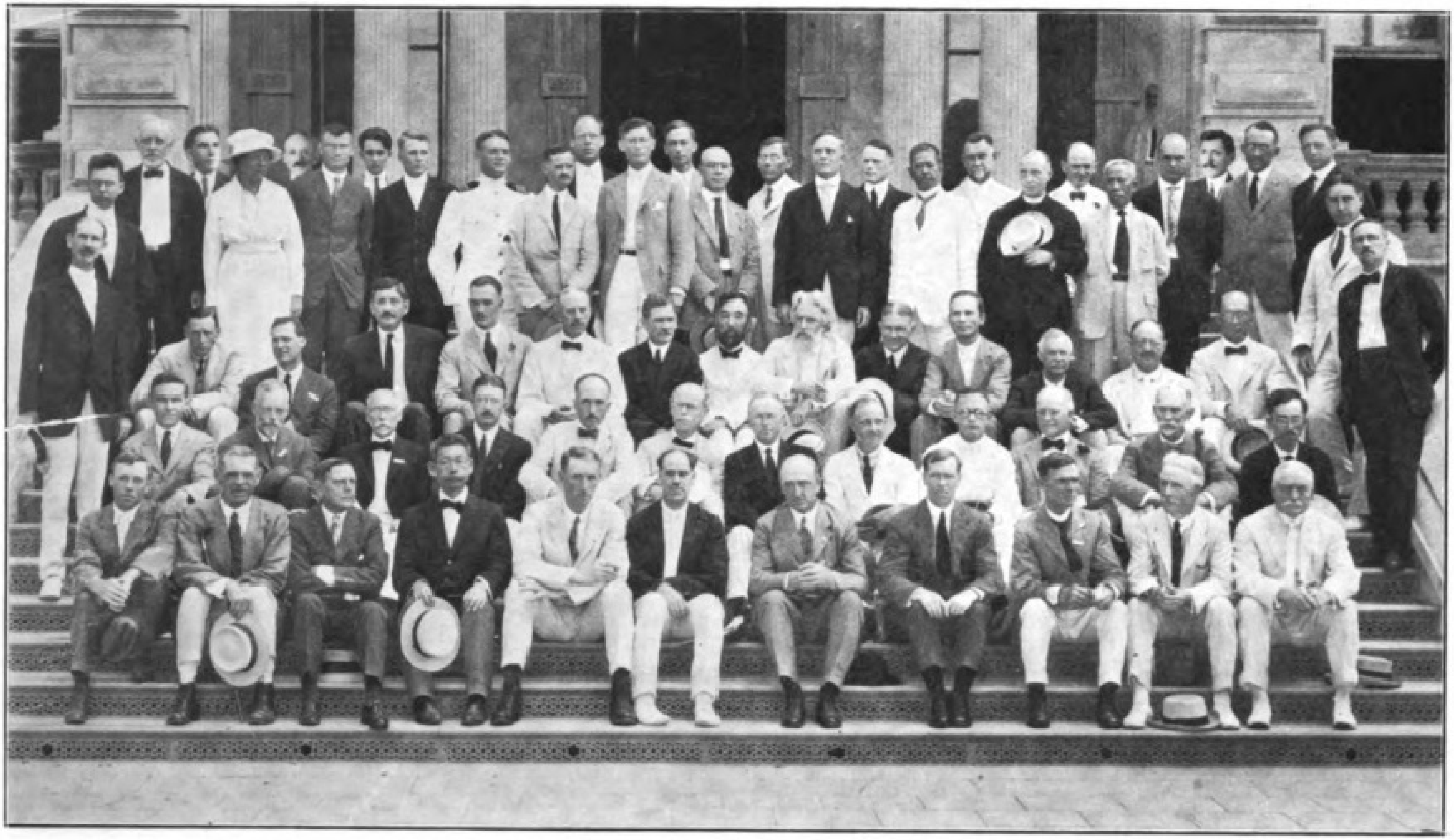
SPECIAL PUBLICATION NUMBER 7, PART I, 1921

Honolulu, Hawaii
Honolulu Star-Bulletin, Ltd.
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DELEGATES TO PAN-PACIFIC SCIENTIFIC CONFERENCE

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INTRODUCTION

HISTORICAL SKETCH AND ACKNOWLEDGMENTS

BY HERBERT E. GREGORY, Chairman of the Conference

The study of the natural history of the Pacific has proceeded with few interruptions since the memorable observations of Captain Cook made the ocean generally known. The results of such surveys as are recorded in Voyage de La Pérouse; Voyage de *L'Astrolabe;* Voyage of the *Beagle;* the Wilkes Exploring Expedition; the *Challenger* Expedition; the Nederlandsche Nieuw Guinea Expédition, the Voyage of the *Discovery;* the Harriman Alaska Expedition; and the British Antarctic Expedition are the foundation stones for Pacific science on which rest the contributions of many individuals and institutions. The interest in systematic exploration during the past decade may be illustrated by the interchange of views that may be considered as the steps leading to the organization of the First Pan-Pacific Scientific Conference—a conference which is "first" only with respect to scope and personnel.

The desirability of a fuller knowledge of the Pacific was considered at the Australian meeting of the British Association for the Advancement of Science (1914), unhappily interrupted by the declaration of war. In 1916 Professor W. M. Davis, who had attended the sessions at Sydney, arranged a symposium on Pacific exploration for the annual meeting of the National Academy of Sciences, and my presence in New Zealand and Australia permitted an exchange of views with scientists of the southern Pacific. In 1918 a conference on international relations, in which Pacific scientific problems received attention, formed part of the program of the Semi-Centennial Anniversary of the University of California. At the close of the anniversary meetings in which Dr. Evermann, Dr. Merriam and Professor Ritter took important parts, the representatives from the countries of the Pacific expressed a desire to call another conference (possibly in Japan) soon after the close of the war. During 1919 continued interest was shown by a paper on Plans for the Exploration of the Pacific presented by invitation at the annual meeting of the National Academy, and by the program of the Pacific Division of the American Association for the Advancement of Science, which included a series of papers on the exploration of the North

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Pacific Ocean. During 1920 the Committee on Pacific Exploration, originally appointed by the National Academy, was transferred to the National Research Council, and, with changes in membership and title, constitutes the present Committee on Pacific Investigations.

The meetings and informal conferences preceding 1920 brought out clearly the size and complexity of the scientific problems centering in the Pacific and the advisability of enlisting the interest of many institutions, individuals and governmental agencies in a combined attack. It became increasingly clear that a study of Pacific problems could be facilitated by a conference of interested scientists in Japan, Canada, China, Australia, New Zealand, Java, continental United States, Hawaii, and the Philippines and steps leading to such a conference were taken.

While plans were being considered a way was unexpectedly opened for holding such a conference in Honolulu under the auspices of the Pan-Pacific Union, an organization designed for promoting good-fellowship among peoples bordering the Pacific.

In April, 1919, the legislature of the Territory of Hawaii appropriated funds to be used by the Pan-Pacific Union in defraying the expenses of a "Pan-Pacific Commercial and Educational Congress" during 1920 or 1921, and the Governor of the Territory placed the organization of the proposed conference in charge of a committee composed of representative citizens of Honolulu with George P. Denison as chairman (see page 3). Meetings of this Committee on July 14th and subsequent dates resulted in a decision to give the 1920 session of the proposed congress the form of a conference dealing with the fundamental scientific problems of the Pacific. This action was so completely in harmony with the plans of the National Research Council and of similar bodies in other countries that the request of the Committee that the Director of the Bernice P. Bishop Museum accept the temporary chairmanship of the scientific congress, determine its scope and personnel, and perfect a preliminary organization, was granted by the Trustees of the Museum.

After consultation with scientists in Honolulu, the Temporary Chairman obtained the consent of the Committee on Pacific Exploration of the National Research Council to serve as a program committee for the coming congress, and at meetings in San Francisco, New York, Boston, and Washington, and through extensive correspondence with institutions and individuals inter-

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ested in the Pacific work, the scope and purpose of the congress and the list of desired delegates were determined.

Early in April, 1920, invitations in the name of the Pan-Pacific Union were sent by the Temporary Chairman to scientists and scientific institutions, and complimentary invitations were sent by the Secretary of the Union to heads of governments, newspapers, and to distinguished citizens in Honolulu and elsewhere. Accompanying the invitation was the Bulletin of the Pan-Pacific Union for May, 1920, and a descriptive circular, from which is taken the following:

The purpose of the congress is to outline scientific problems of the Pacific Ocean region and to suggest methods for their solution; to make a critical inventory of existing knowledge, and to devise plans for future studies. It is anticipated that this congress will formulate for publication a program of research which will serve as a guide for coöperative work for individuals, institutions, and governmental agencies.

The program of the Conference is in the hands of the Committee on Pacific Exploration of the National Research Council.

The meetings will be arranged to place emphasis on the following topics:

1. The present status of knowledge of the various branches of anthropology, biology, geography, geology, and related sciences in so far as the Pacific Ocean region is concerned.

2. Research desirable to inaugurate; projects described in considerable detail with reference to their significance, and their bearing on other fields of study. Investigations designed to lay the foundation for a higher utilization of the economic resources of the Pacific may be included.

3. Methods of coöperation with a view to eliminating unnecessary duplication of money and energy.

4. The best use of the funds now available and the source of further endowments.

As shown by the list of delegates (pp. 22-26) the response to the invitations was unexpectedly gratifying but the Conference would have profited much by the presence of such men as W. M. Davis, R. Daly, S. Percy Smith, L. O. Howard, J. C. Merriam, W. E. Ritter, E. Edgeworth David, and T. F. Cheeseman, debarred by illness or important engagements; and of Father Rougier and G. H. Angenheister prevented from attending by lack of transportation—all of whom contributed from their store of knowledge and experience to the success of the gathering.

The three months immediately preceding the meeting of the Conference were devoted to enlisting the interest of governmental bureaus, institutions, and individuals and in perfecting local plans for organization. On June 17, 1920, the Trustees of the Pan-Pacific Union officially approved the formal and informal actions

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of the Committee of the Pan-Pacific Union, and in order to meet the restrictions of the appropriation by the Territory the forthcoming congress was given the official title: "The First Pan-Pacific Scientific Conference of the Commercial and Educational Congress." To complete the necessary organization a Committee on Arrangements and a Committee on Publications were appointed (see page 3), and funds were allotted for expenses of delegates, publication of proceedings, and for general purposes.

After the preliminary organization of the Conference had been effected the duties of the Temporary Chairman and of the preliminary Committee on Program came to an end. The Committee of the Pan-Pacific Union, the Committee on Arrangements, and the Committee on Publication continued to function but the Conference itself was completely autonomous, electing its chairman and other officers and its committees, arranging its program and making provision for future meetings. (See pages 3 and 10.)

The Conference was designed as a gathering of scientists directly interested in the solution of problems centering in the Pacific. The delegates from the various countries were invited as individuals, and not as official representatives of governments or institutions. As was to be expected in a body so chosen, racial, national and institutional interests were completely submerged in the desire for helpful coöperation.

The Pan-Pacific Union and the Conference are under great obligations to the individuals and the institutions that generously gave of their time and means to make the sessions profitable. The Committee on Arrangements (see page 3), under the leadership of Mr. J. R. Galt, were constantly on the alert to provide the delegates with congenial surroundings and with facilities for their work. Outstanding features of the program planned by this Committee are:

1. Informal conferences with educational, commercial and military leaders and the interesting public lectures: The Sugar Industry of Hawaii, by E. Faxon Bishop; The Pineapple Industry of Hawaii, by Dr. H. L. Lyon; The Wireless Communications of Hawaii, by J. A. Balch: The History of Volcanic Eruptions in Hawaii, by Lorrin A. Thurston, and Hawaiian Trails and Mountains, by Vaughan MacCaughey.

2. Military review by the 17th Cavalry, Colonel J. D. L. Hartmann, Commanding Officer, by courtesy of Brigadier-General H. C. Hodges, Jr., Post Commander, Schofield Barracks.

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3. Complimentary excursions by automobile around the island of Oahu and by train over the lines of the Oahu Railway and the Hawaii Consolidated Railway.

4. Financial arrangements which made it possible for the Conference to hold a fully attended six-day session on the island of Hawaii.

5. Guest cards issued to delegates by the Commercial Club, the Country Club, the Pacific Club and the University Club.

6. The thoughtfully planned receptions given by the Bishop Museum and by the University of Hawaii, and the smokers arranged by the Country Club and by the University Club, which served to establish friendly relations between the people of Honolulu and the visiting delegates.

7. The dinner given by the Governor of Hawaii, the "chowder supper" of the Pacific Club at the home of Mr. John Guild, and the Conference dinner of the Pan-Pacific Union.

The cordiality of the hosts, the brilliant speeches, and the unique entertainments made those gatherings memorable events in the minds of the distinguished company present. Further appreciation by the Conference of the assistance rendered by the people of Hawaii is fittingly expressed in the widely distributed pamphlet prepared by the Committee on Resolutions of Thanks and Appreciation: Henry S. Washington, Chairman; E. C. Andrews; Charles Chilton; Elmer D. Merrill; and Fusakichi Omori.

In recognition of good will extended to them, nearly all of the visiting delegates responded to requests for addresses before the various clubs and societies in Honolulu and public lectures were delivered by Dr. William Bowie, Professor Charles Chilton, Dr. Alfred Mayor, and Dr. Elmer D. Merrill. Public lectures in the Japanese language were delivered by Professors K. Kishinouye, F. Omori, K. Shibata, and N. Yamasaki.

The Conference is indebted to several organizations and individuals for the loan of books and specimens and to the United States Geological Survey, the United States Navy, and to the Japanese Government for useful charts and diagrams.

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STATEMENT OF COMMITTEE ON PUBLICATION

By Arthur L. Dean, Chairman of the Committee

A Committee on Publication was appointed by the President of the Pan-Pacific Union in July preceding the opening of the Conference (see page 3). This Committee had the active cooperation of the secretaries of the sections in securing reports of the section meetings.

The manuscripts submitted by authors and the stenographic reports of discussions based on the stenographic record skillfully compiled by Olga Smith, Marie Neal, Anne Satterthwaite, and Marie Gregory have been selected and arranged as follows: papers on anthropology, by Clark Wissler; papers on botany by W. E. Safford; papers on biology, by Paul Bartsch, C. H. Edmondson, H. F. Moore, and F. Muir; on geography, by William Bowie and George F. McEwen; papers on general geology, by Herbert E. Gregory and T. Wayland Vaughan; papers on volcanology and seismology, by T. A. Jaggar, H. S. Washington, and H. O. Wood; and other material by the members of the Committee on Publication resident in Honolulu. To fill undesirable gaps in the presentation of certain topics, the Committee has received the generous assistance of scientists who were unable to attend the meetings of the Conference.

Because of limitations of space, the Committee has abstracted or curtailed certain articles and has reluctantly returned several important manuscripts to their authors. As indicated in the following pages, some of these manuscripts have already been published elsewhere. The others are expected to appear in appropriate journals or transactions.

As announced by the Committee on April 4th, it has been found impracticable to submit proof to all the widely separated authors. Residents of Hawaii and members of the staff of Scripps Institution have had opportunity to see their contributions in the galley form. Proofs of the preliminary pamphlets (pp. 1-46 of Part I) were read by Miss Olga Smith and Arthur L. Dean. Proofs of the remaining pages were read by Miss Bertha Metzger and by Herbert E. Gregory, and also, for their respective branches of science, by Ralph Linton, ethnologist; H. F. Bergman, botanist; C. H. Edmondson, zoologist; T. A. Jaggar, Jr., volcanologist; Arnold Rom-

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berg, seismologist; Lawrence Daingerfield, meteorologist; H. S. Palmer, geologist. Proof of the sections on Methods of Cooperation and Training of Scientists and Addresses of Welcome were read by Arthur L. Dean. It is hoped that this procedure has resulted in no serious errors in statement or context.

The titles of the delegates have been published in the list on pages 22 to 26 and are not repeated elsewhere: the titles of non-delegates are printed where their names occur.

It has been found desirable to issue the Proceedings in three volumes bound as Part I, containing the Introduction and pages 1 to 308; and Part II, containing pages 309 to 636; and Part III, containing pages 637 to 949. With the title "First Pan-Pacific Scientific Conference; Organization, Proceedings, Resolutions," pages 1 to 46 of Part I were separately issued as a pamphlet in November, 1920.

The Committee regrets its inability to publish these Proceedings at an earlier date. The fact that the members have been widely separated and have been obliged to rely upon correspondence to a considerable degree has delayed their work, a delay which was increased because of the necessity for correspondence and interchange of manuscripts with delegates residing in different countries. It has been the belief of the Committee that the importance of the work of the Conference justified a comprehensive treatment of many important topics and the inclusion of papers from sources outside the Conference itself. It is believed that these Proceedings are fundamental and define the problems of the Pacific, both in respect to what is already known and to the program for the future. The thanks of the Committee and of all who are interested in scientific work in the Pacific are due to those contributors who were not able to be present at the Conference, as well as to all who have assisted in the work of publication.

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ORGANIZATION

Chairman..HERBERT E. GREGORY
Vice-Chairman and Secretary.............ARTHUR L. DEAN

EXECUTIVE AND PROGRAM COMMITTEE

The Chairman, the Vice-Chairman and the Leaders of the Sections.

COMMITTEE ON PUBLICATIONS.

Arthur L. Dean, Chairman. T. Wayland Vaughan, Henry S. Washington, Herbert E. Gregory.

COMMITTEE OF THE PAN-PACIFIC UNION.

George P. Denison, Chairman. F. C. Atherton, C. K. Ai, W. R. Castle, W. F. Frear, A. Lewis, Jr., Prince Kuhio Kalanianaole, Vaughan MacCaughey, I. Mori, R. H. Trent; Ex-officio: the President, Secretary and Treasurer of the Pan-Pacific Union.

COMMITTEE ON ARRANGEMENTS.

John R. Galt, Chairman. Robbins B. Anderson, Lyman H. Bigelow, C. H. Edmondson, Alonzo Gartley, T. A. Jaggar, Jr., Lorrin A. Thurston, Gerrit P. Wilder. Secretary, Miss A. Y. Satterthwaite.

ORGANIZATION OF SECTIONS.

ANTHROPOLOGY

Leader, Clark Wissler, Curator of Anthropology, American Museum of Natural History, New York City.

Secretary, John F. G. Stokes, Anthropologist, Bernice P. Bishop Museum, Honolulu.

BIOLOGY

Leader, Charles Chilton, Professor of Biology, Canterbury College, Christchurch, New Zealand.

Secretary, C. H. Edmondson, Professor of Zoology, University of Hawaii.

BOTANY

Leader, W. E. Safford, Economic Botanist, United States Department of Agriculture.

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Secretary, Charles N. Forbes, Curator of Botany, Bishop Museum; Mrs. Forest B. H. Brown, Research Associate in Botany, Bernice P. Bishop Museum, Honolulu.

ENTOMOLOGY

Leader, F. Muir, Entomologist, Hawaiian Sugar Planters' Association.

Secretary, D. T. Fullaway, Entomologist, Board of Agriculture and Forestry, Territory of Hawaii.

GEOGRAPHY

Leader, William Bowie, Chief Division of Geodesy, United States Coast and Geodetic Survey.

Secretary, G. W. Littlehales, Geographer, U. S. Bureau of Navigation.

Sub-Sections: Geodesy and Topography, N. Yamasaki, Chairman; Terrestrial Magnetism, J. T. Watkins, Chairman; Meteorology, L. H. Daingerfield, Chairman; Physical Oceanography, G. F. McEwen, Chairman.

GEOLOGY

Leader, T. Wayland Vaughan, United States Geological Survey.

Secretary, Harold S. Palmer, Assistant Professor of Geology, University of Hawaii.

SEISMOLOGY AND VOLCANOLOGY

Leader, Fusakichi Omori, Director, Seismological Institute, Tokyo, Japan.

Secretary, T. A. Jaggar, Jr., Director, Hawaiian Volcano Research Observatory.

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PROCEEDINGS OF THE GENERAL SESSIONS

MONDAY, AUGUST 2, 9:00 a. m.

Chairman: Herbert E. Gregory.

Addresses of Welcome.

Hon. C. J. McCarthy, Governor of Hawaii.

Hon. George R. Carter, ex-Governor of Hawaii.

A. L. Dean, President, University of Hawaii.

H. P. Agee, Director, Experiment Station of the Hawaiian Sugar Planters' Association.

A. F. Judd, President, Board of Trustees, Bernice Pauahi Bishop Museum.

Addresses on Salient Features of Science in Hawaii.

William T. Brigham: Anthropology.

Charles N. Forbes: Botany.

Otto H. Swezey: Entomology.

H. A. Pilsbry: Conchology.

Read by Title.

Charles H. Edmondson: Marine Biology.

Lawrence H. Daingerfield: Meteorology.

T. A. Jaggar: Volcanology.

MONDAY, AUGUST 2, 2:00 p. m.

Chairman: Herbert E. Gregory.

Organization of the Conference.

Following preliminary statements regarding the plans for entertainment and the trip to Hawaii, the Chairman opened the subject of the organization of the Conference. It was

Voted: That the Chairman, Vice-Chairman, and the Leaders of the Sections constitute an executive and program committee.

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TUESDAY, AUGUST 3, 9:00 a. m.

Chairman: C. M. Fraser.

Subject: Ocean Currents and Their Significance.

George F. McEwen: The Pacific Ocean and Its Importance to Pacific Countries.

G. W. Littlehales: The Hydrographic Aspects of Ocean Currents.

N. Yamasaki: Oceanographic Research in Japan.

Lawrence H. Daingerfield: Meteorological Aspects of Ocean Currents.

R. A. Daly, of Harvard University: Some Suggestions for Geological Research in the Pacific Islands. (Read by the Secretary.)

R. C. Wells: Chemistry of Natural Waters.

H. S. Washington: Relations of Geological Change to Ocean Currents.

Wm. Bowie: Influence of Isostasy on Ocean Currents.

J. T. Watkins: Inshore Currents.

WEDNESDAY, AUGUST 4.

No general sessions. The delegates made the trip around the island of Oahu with informal addresses at points of interest.

THURSDAY, AUGUST 5, 9:00 a. m.

Chairman: Joseph A. Cushman.

Subject: Hawaiian Flora and Fauna.

Forest B. H. Brown: The Origin of Hawaiian Flora.

F. Muir: The Origin of the Hawaiian Flora and Fauna.

H. A. Pilsbry: The Dispersal and Affinities of Polynesian Land Snail Faunas.

W. A. Bryan: Origin of Hawaiian Flora and Fauna.

Discussion by: Alfred G. Mayor, William E. Safford, Paul Bartsch, H. A. Pilsbry.

FRIDAY, AUGUST 6, 9:00 a. m.

Chairman: F. Wood-Jones.

Subject: Race Relations in the Pacific.

H. E. Gregory: The Dominick Expedition.

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A. G. Mayor: Similarity Between Japanese and Polynesians.

A. F. Judd: Scarcity of Proper Wall Maps and Teachers Familiar With Geography of Pacific Lands.

Clark Wissler: Man in the Pacific.

A. L. Kroeber: Anthropology of the Philippines.

L. R. Sullivan: Physical Anthropology in Polynesia.

Alfred Tozzer: Anthropological Study of the Hawaiian Race.

J. F. G. Stokes: Religious Significance of Polynesian Feather Work.

T. G. Thrum: Hawaiian Archaeology—Temple Structure.

Discussion by: W. E. Safford, Chas. Hedley, A. G. Mayor, Forest Brown.

SATURDAY, AUGUST 7, 9:00 a. m.

Chairman: Leo A. Cotton.

Subject: Relation of Ocean Currents to Marine Organisms.

Paul Bartsch: Ocean Currents, the Prime Factor in the Distribution of Marine Mollusks on the West Coast of America.

H. F. Moore: Relation of Ocean Currents to Fish.

T. C. Frye: Ocean Currents and the Problem of More Food for Man.

Wm. E. Safford: Dispersal of Plants by Ocean Currents.

Discussion by: H. A. Pilsbry, G. F. McEwen, T. Wayland Vaughan, Charles Hedley, G. W. Littlehales, A. G. Mayor, Charles Chilton, C. M. Fraser.

AUGUST 8 to AUGUST 13

The delegates visited the Islalnd of Hawaii, devoting special attention to the crater of Kilauea.

SATURDAY, AUGUST 14, 9:00 a. m.

Chairman: T. Wayland Vaughan.

Subject: The Framework of the Pacific.

E. C. Andrews: The Structural Unity of the Suboceanic Mass of the Pacific Ocean.

R. T. Chamberlin: Framework of the Pacific and Its Relation to the Americas.

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F. Omori: Geographic Distribution of Volcanoes in the Pacific.

Wm. Bowie: The Bearing of Geodetic Investigation on the Knowledge of the Geologic Structure of the Pacific.

Discussion by: H. S. Washington, C. A. Sussmilch, T. A. Jaggar, W. D. Smith, L. A. Cotton, Wm. Bowie, R. C. Wells,

MONDAY, AUGUST 16, 9:00 a. m.

Chairman: J. Allan Thomson.

Subject: Mapping of the Pacific.

William Bowie: Shore Lines of the Pacific.

G. R. Davis: Coast and Island Topography.

T. Wayland Vaughan: Sedimentation and Bottom Configuration.

George F. McEwen: Recommendations Concerning Investigations of the Pacific Ocean Waters.

G. W. Littlehales: The Deeps of the Pacific Ocean.

N. Yamasaki: Islands of the South Pacific.

J. T. Watkins: The Survey of the Shoreline and Coastal Waters of the Pacific Ocean.

E. A. Beals: The Importance for Weather Forecasting of a Thorough Knowledge of the Pacific.

Discussion by: H. F. Moore, Paul Bartsch, H. C. Richards, L. A. Cotton, C. M. Fraser, J. Allan Thomson, A. G. Mayor, T. Wayland Vaughan, R. C. Wells.

TUESDAY, AUGUST 17, 9:00 a. m.

Chairman: Elmer D. Merrill.

Subject: Presentation by Sections of Programs of Research.

The Leaders reported the resolutions recommended by their Sections.

Clark Wissler: For the Section of Anthropology.

C. M. Fraser: For the Section of Biology.

Wm. E. Safford: For the Section of Botany.

Wm. Bowie: For the Section of Geography.

T. Wayland Vaughan: For the Section of Geology.

T. A. Jaggar, Jr.: For the Section of Seismology and Volcanology.

Following the discussion of the resolutions it was

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Voted: To print the proposed resolutions and distribute copies among the delegates for their study.

Voted: To refer the proposed resolutions to the Publication Committee for revision with instructions to report back to the general session of the Conference to be held August 20.

WEDNESDAY, AUGUST 18, 9:00 a. m.

Chairman: N. Yamasaki.

Subject: Training of Scientists for Pacific Work.

Addresses by: A. L. Dean, Wm. Bowie, H. C. Richards, W. E. Safford, A. F. Judd, E. C. Andrews, B. W. Evermann, Paul Bartsch, Chas. Chilton, H. E. Gregory, Josephine Tilden, L. A. Cotton, C. M. Fraser, T. W. Vaughan.

THURSDAY, AUGUST 19, 9:00 a. m.

Chairman: C. A. Sussmilch.

Subject: Means and Methods of Cooperation.

The following delegates addressed the conference in behalf of the several institutions represented by them.

H. C. Richards: The University of Queensland.

Barton W. Evermann: The California Academy of Sciences.

J. Allan Thomson: The Government of New Zealand, Institutions of New Zealand and Individual Scientists.

C. M. Fraser: The Biological Station, Nanaimo, B. C.

Charles Hedley: The Australian Museum, Sydney.

John B. Henderson: The United States National Museum.

K. Kishinouye: Japan.

George F. McEwen: The Scripps Institution for Biological Research, of the University of California.

William E. Ritter: (Read by G. F. McEwen)—The Role of the Scripps Institution in a Program of Pacific Exploration.

A. F. Judd: The Bernice P. Bishop Museum.

H. A. Pilsbry: The Philadelphia Academy of Sciences.

Elmer D. Merrill: The Philippine Bureau of Science.

E. O. Hovey: The American Museum of Natural History.

William E. Safford: The United States Department of Agriculture.

Charles Chilton: Canterbury College, Christchurch, N. Z.

H. F. Moore: The United States Bureau of Fisheries.

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T. C. Frye: The Puget Sound Biological Station of the University of Washington.

Josephine Tilden: Inland Universities.

FRIDAY, AUGUST 20, 9:00 a. m.

Chairman: A. L. Dean.

Subject: Adoption of Resolutions.

Resolutions were presented by:

F. Wood-Jones on Anthropology,

Charles Chilton on Biology,

W. E. Safford on Botany,

William Bowie on Geography,

T. Wayland Vaughan on Geology,

T. A. Jaggar, Jr., on Seismology and Volcanology.

General Resolutions were presented by:

H. E. Gregory on Ships for Exploration,

William Bowie on the International Research Council,

H. E. Gregory on Future Conferences.

H. E. Gregory on Permanent Organization,

A. L. Dean on Promotion of Education.

The resolutions as adopted are printed elsewhere.

H. S. Washington presented a resolution thanking the institutions and individuals in Hawaii whose cooperation and hospitality had contributed to the success of the Conference and the pleasure of the Delegates.

It was voted to request the Bishop Museum to preserve the records of the Conference, to publish and distribute the reports, papers and proceedings, and to act as representative of the members of the Conference after its adjournment.

It was voted that the Delegates from each country represented at the Conference elect one of their number to serve on a committee to arrange for future Conferences. The following were selected to serve with Herbert E. Gregory: E. C. Andrews, Australia; C. M. Fraser, Canada; F. Omori, Japan; Charles Chilton, New Zealand; T. Wayland Vaughan, United States.

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PROCEEDINGS OF THE SECTIONS.

SECTION OF ANTHROPOLOGY.

Monday, August 2.

The Section was organized with Clark Wissler, Leader, and J. F. G. Stokes Secretary. The work of the Section was outlined.

Tuesday, August 3.

On plans for an extended exploration of the Pacific, and on the characteristics of the Hawaiians in 1864-5. William T. Brigham.

Thursday, August 5.

Report of the Archaeological Committee, presented by J. F. G. Stokes.

Report of the Committee on Linguistics, presented by A. L. Kroeber.

Friday, August 6.

Hawaiian Temples. Thomas G. Thrum. Read by Gerard Fowke.

Anthropology of Formosa. N. Yamasaki.

Kitchen Middens of Japan. K. Kishinouye.

Anthropology in Australia. F. Wood-Jones.

Influence of Insects on Race Distribution. F. Muir

Monday, August 16.

Notes on the Migrations and Dispersals of the Polynesians. J. F. G. Stokes.

Alleged Similarity of Fortified Villages in New Zealand and Fiji. J. Allan Thomson.

Committee appointed to formulate a statement regarding the value of records of early Spanish and Whaling Voyages.

Tuesday, August 17.

Report of Committee on Spanish and Whaling Voyages, presented by F. Wood-Jones.

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Letter from Charles B. Davenport on the "Type Unit" Method of investigation.

Letter from David Fairchild of the American Genetic Association on the subject of heredity.

Consideration of resolutions to be presented to the general sessions of the Conference.

Suggestions on botanical methods calculated to be of ethno-botanical value. Miss Josephine Tilden. Read by the Chairman.

SECTION OF BIOLOGY.

Monday, August 2.

Section organized with Charles Chilton, Leader, and C. H. Edmondson, Secretary. The program of work for the Section was outlined.

Tuesday, August 3.

Discussion of the distribution of animals in the Pacific.

Joseph A. Cushman: Distribution of Foraminifera.

Paul Bartsch, John B. Henderson, and Henry A. Pilsbry: Distribution of Mollusca.

Charles Chilton: Distribution of Amphipods and Isopods.

F. Muir and O. H. Swezey: Distribution of Insects.

Charles H. Edmondson: Shallow Water Crustacea.

K. Kishinouye: Relationships of the Fauna of Japanese Waters.

C. M. Fraser: Distribution of Hydroids.

T. Wayland Vaughan: Distribution of Corals.

The general conclusion was that the weight of evidence supports a closer relationship with Indo-Pacific forms than with those of American shores.

Thursday, August 5.

Illustrated lecture, New Zealand's Call to the Botanist, by Charles Chilton.

Friday, August 6.

Joint meeting with Section of Geology. For program see report of Geology Section.

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Saturday, August 14.

The Fisheries of Japan. K. Kishinouye.

Ocean Pastorage and Ocean Fisheries, a paper sent to the Conference by W. E. Allen of the Scripps Institution for Biological Research of the University of California.

The Necessity for Conservation of Fish Resources. Barton W. Evermann.

Further Data Showing the Necessity for Conservation of the Fish Supply. C. M. Fraser.

The Present Inadequacy of Statistics of Fisheries. H. F. Moore.

Monday, August 16.

Joint Meeting of the Sections of Botany and Zoology devoted to discussion of Biological Stations and other Scientific Institutions bordering the Pacific.

The Biological Station, Nanaimo, British Columbia. C. M. Fraser.

The Biological Station, Friday Harbor. T. C. Frye.

The Biological Station of Minnesota. Miss Josephine E. Tilden.

The Biological Station of California, and the Work of the Fish and Game Commission. Barton W. Evermann.

Biological Station in Australia. Chas. Hedley.

The Work of the National Museum. Paul Bartsch.

The Work of the Boston Society of Natural History. Joseph E. Cushman.

The work of the Natural History Society of Philadelphia. H. A. Pilsbry.

Biological Work in Japan. K. Kishinouye.

The Work of the Philippnie Bureau of Science. Elmer D. Merrill.

The Work in Entomology in Honolulu. O. H. Swezey.

The Biological Station of the University of Hawaii. C. H. Edmondson.

The Bureau of Fisheries. H. F. Moore.

The Biological Station of New Zealand. Charles Chilton.

Consideration of resolutions to be presented to the general Conference.

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Tuesday, August 18.

Experimens on the Growth of Reef Organisms. Frank Potts.

Discussion of the effect of temperature on the size of marine organisms, participated in by C. M. Fraser, H. F. Moore, C. H. Edmondson, B. W. Evermann, Paul Bartsch.

Breeding Experiments. Paul Bartsch.

Presentation of proposed program of research in Pacific Ocean Algae by Miss Josephine E. Tilden.

Wednesday, August 19.

Discussion of resolutions to be presented to the general Conference.

SECTION OF BOTANY.

Monday, August 2.

Section organized with William E. Safford, Leader, and C. N. Forbes, Secretary. The work of the Section was outlined.

Ethno-Botany of the Polynesians. William E. Safford.

Tuesday, August 3.

The American Element in Hawaiian Vegetation. Forest B. H. Brown.

Cultivated Plants of the Pacific Islands as an Index to the Migrations of the Polynesians. W. E. Safford.

Thursday, August 5.

Joint meeting of the Sections of Botany and Zoology.

New Zealand's Call to the Botanist, an illustrated lecture by Charles Chilton.

Friday, August 6.

The Tapestry Forests of the Island of Oahu. Vaughan MacCaughey.

Saturday, August 14.

Owing to the death of Charles N. Forbes, Mrs. Forest Brown was appointed secretary.

Some Problems in Plant Physiology and Ecology in Hawaii. H. F. Bergman.

The Field Label in Botany. Elmer D. Merrill.

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Monday, August 16.

Joint meeting of the Section of Botany with the Section of Biology. For program see "Section of Biology."

Wednesday, August 18.

The Flora and Phytogeography of Japan and Adjoining Regions. K. Shibata.

Notes on the Algae of the Northwest Coast. T. C. Frye.

The Medicinal Plants of the Philippines. Leon M. Guerrero.

SECTION OF ENTOMOLOGY.

Wednesday, August 4.

Section organized with F. Muir, Leader, and D. T. Fullaway, Secretary.

Assignment of topics to members of the Section.

Tuesday, August 17.

Some Problems in Hawaiian Entomology. F. Muir.

Need of Further Exploration and Study of the Hawaiian Insect Fauna and Value of Such Study in the Exploration of the Pacific. O. H. Swezey.

Some Aspects of Economic Entomology in Hawaii. D. T. Fullaway.

What Horticultural Inspection Has Done and Can Do for Hawaii. E. M. Ehrhorn.

Ideas on How an Entomological Expedition Should be Conducted. F. X. Williams.

Medical Entomology. D. L. Crawford.

Discussion on the necessity for further entomological exploration in the Pacific area.

SECTION OF GEOGRAPHY.

Monday, August 2.

Section organized with William Bowie, Leader, and G. W. Littlehales, Secretary. The work of the Section was outlined.

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Tuesday, August 3.

Observations of Temperature and Salinity at Selected Coastal Stations in Japan; accompanied by an index-chart showing the location and extent of regularly observed hydrographical sections on the coast of Japan. K. Kishinouye.

The Desirability of Supplying Information in Greater Detail Upon Sea Charts. N. Yamasaki.

The Extent to which the Contours of Configuration of the Basin of the Pacific Ocean have been Made Known by Deep-sea Soundings; including an account of methods of deep-sea soundings, and of the mathematical investigations which have been made to define the theoretical form of isolated submarine peaks, and the intervals which should obtain between deep-sea soundings to disclose the topography of the bottom of the ocean. G. W. Littlehales.

The Investigations in Physical Oceanography of the Scripps Institution of the University of California. George F. McEwen.

Thursday, August 5.

The Growth and Present Extent of Ocean Magnetic Surveys, with an account of the investigations in Terrestrial Magnetism by American Institutions. J. T. Watkins.

The Purposes, Instruments and Methods of the Hawaiian Magnetic Observatory, with Its Records and Publications. Harold McComb.

On the Atmospheric Electricity of the Hawaiian Islands. Lawrence H. Daingerfield.

Friday, August 6.

Meteorological Centers of Action in the North Pacific Ocean. E. A. Beals.

Researches in the Geodetic Work of the Pacific. William Bowie.

Saturday, August 14.

Extent of Geographical Surveys in the Hawaiian Islands. George R. Davis.

Monday, August 16.

Low-Sun Phenomena in Luzon. Willard J. Fisher.

Tropical Geology and Engineering. Warren D. Smith.

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Tuesday, August 17.

Consideration of resolutions to be presented to the general sessions of the Conference.

Wednesday, August 18.

Consideration of resolutions to be presented to the general sessions of the Conference.

SECTION OF GEOLOGY.

Monday, August 2.

T. Wayland Vaughan was selected Leader of the Section. The Chariman outlined the work before the Section and a tentative program was arranged.

Tuesday, August 3.

Harold S. Palmer was appointed Secretary of the Section. Presentation of formal papers was postponed until the arrival of the delegates from the south and west.

Thursday, August 5.

The Structural Framework of the Pacific. E. C. Andrews.

The Melanesian Plateau, with Especial Reference to the Land Shell Fauna. Charles Hedley.

Salient Features of the Geologic Structure of the Philippine and Neighboring Islands. Warren D. Smith.

The Essential Structural Features of Japan. N. Yamasaki.

The Relation of Gravimetric Surveys to the Framework of the Pacific Region. William Bowie.

The Structure of the Cordilleras of North and South America. Rollin T. Chamberlin.

The Structure of the Caribbean Region. T. Wayland Vaughan.

Letters from Professor Bailey Willis of Stanford University and Dr. Alfred H. Brooks of the U. S. Geological Survey were read.

Friday, August 6.

The Basis of the Correlation of the Tertiary and Quaternary Geologic Formations of the Pacific Islands. T. Wayland Vaughan.

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Correlation of the Tertiary of Australia and Adjoining Regions. C. A. Sussmilch.

Correlation of the Geologic Formations of Australia. E. C. Andrews.

The Stratigraphy of the Philippine Islands. Warren D. Smith.

The Fossil and Existing Foraminifera of the Atlantic and Pacific Regions. Joseph A. Cushman.

The distribution of the molluscan fauna was discussed by H. A. Pilsbry, and that of the Foraminifera by T. W. Vaughan.

Saturday, August 14.

Geodetic Research in the Pacific Region. William Bowie: listened to jointly by the Sections of Geology and Geography.

The Status of Areal Geologic Mapping in the Pacific Region was discussed by T. Wayland Vaughan for the Americas: by J. Allan Thomson for New Zealand; by E. C. Andrews for New South Wales and the outer islands; by H. C. Richards for the rest of Australia; and by N. Yamasaki for Japan, Korea and China.

It was proposed to summarize the progress in the Pacific region by a series of key maps. The work was divided as follows:

New Zealand	J. Allan Thomson
Australia	E. C. Andrews
The Philippines	W. D. Smith
Japan, Korea and China	N. Yamasaki
North and South America and Dutch East Indies	T. Wayland Vaughan
Antartica	L. A. Cotton

Monday, August 16.

Indurated Glacial Clays from Australia. C. A. Sussmilch.

The Status of Areal Geologic Mapping in the Philippines. Warren D. Smith.

A letter from Dr. Alfred H. Brooks pointing out the need of work on the correlation of Alaskan areal stratigraphy with that of eastern Siberia and northwestern Canada was read.

Consideration of resolutions to be presented to the general sessions of the Conference.

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Tuesday, August 17.

The Glaciation of the Mountains in Japan. N. Yamasaki.

Discussion of Glaciation by T. Wayland Vaughan, Rollin T. Chamberlin, C. A. Sussmilch, E. C. Andrews, T. A. Jaggar, Jr., Alfred G. Mayor, Paul Bartsch and W. Alanson Bryan.

The Great Barrier Reef and the Reefs of Fiji. E. C. Andrews.

Coral Reefs on Tutuila. Rollin T. Chamberlin.

The Ecology of the Reef Corals of Tutuila. Alfred G. Mayor.

Chemical Investigations Relating to Corals. Roger C. Wells.

Theories of the Formation of Coral Reefs. T. Wayland Vaughan.

Wednesday, August 18.

Possible Deformation Resulting from Slight Wanderings of the Pole. L. A. Cotton.

Consideration of resolutions for presentation to the general sessions of the Conference.

Thursday, August 19.

Joint meeting with the Section of Volcanology and Seismology.

Earthquake Frequency with Special Reference to Tidal Stresses in the Lithosphere. L. A. Cotton.

Pit Craters and the Persistence of Vents, Henry S. Washington.

The Chairman of the Section of Geology made the following assignments:

Country	Geologic Mapping	Stratigraphic Correlation
New Zealand	J. Allan Thomson	J. Allan Thomson
Australia	E. C. Andrews	H. C. Richards
China, Korea, Japan	N. Yamasaki	N. Yamasaki
North and South America	T. W. Vaughan	T. W. Vaughan
Dutch East Indies	T. W. Vaughan	T. W. Vaughan
Philippine Islands	Warren D. Smith	Warren D. Smith

The work of the Committee on Sedimentation of the Division of Geology and Geography of the United States National Research Council. T. Wayland Vaughan.

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SECTION OF SEISMOLOGY AND VOLCANOLOGY

Monday, August 2.

Section organized with F. Omori, Leader, and T. A. Jaggar, Jr., Secretary. The work of the section was outlined.

The Growth of the Work of the Hawaiian Volcano Research Association. L. A. Thurston.

The Organization of the International Research Council. H. S. Washington.

Tuesday, August 3.

Pulsatory Oscillations. F. Omori.

The Present Status of the Seismological Work in the Pacific, a paper sent to the Conference by Otto Klotz, of the Dominion Observatory, Ottawa, Canada, and read by the Secretary.

Extract from a letter by Harry Fielding Reid of Johns Hopkins University, dealing with seismology in the Pacific.

Thursday, August 5.

Volcano Types and the Chemistry of Magma. H. S. Washington.

Friday, August 6.

Hawaiian Earthquakes. T. A. Jaggar, Jr.

Tectonic Controls in the Case of Volcanic Earthquakes. H. O. Wood.

Volcanic Tremors and Volcanic Earthquakes. F. Omori.

Monday, August 9.

Volcano House, Hawaii.

The Volcanoes of the Pacific. H. S. Washington.

Tuesday, August 10.

Volcano House, Hawaii.

A Program of Experimental Volcanology. T. A. Jaggar, Jr.

Earthquake Zones in and Around the Pacific. F. Omori.

Regional Seismology vs. World Seismology. H. O. Wood.

Saturday, August 14.

Joint meeting with the Section of Geography. For program see report of the Section of Geography.

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Sunday, August 15.

Discussion of the resolutions to be presented to the general Conference.

Monday, August 16.

Report of the Section of Volcanology of the American Geophysical Union. H. S. Washington.

Tuesday, August 17.

Discussion and Drafting of Resolutions.

Wednesday, August 18.

Joint meeting with the section of Geology; for program see report of that Section.

Thursday, August 19.

Joint meeting with the Section of Geology; for program see report of that Section.

The joint meeting was followed by a session of the Section of Seismology and Volcanology in which the following papers were presented.

Seismical Phenomena at Samoa. G. Angenheister; read by Arnold Romberg.

Historical Statement of the Growth of Seismology in the Philippines. M. S. Maso.

Friday, August 20.

Exhibition of records made with a special duplex pendulum, and maps of soundings in Kagoshima Bay before and after eruption of Sakurajima. F. Omori.

Notes on Seismic Triangulation with Instruments of more than one Magnification for Regional Seismometry. H. O. Wood.

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DELEGATES PAN-PACIFIC SCIENTIFIC CONGRESS

AGEE, H. P.,
Agriculturist, Director Experiment Station Staff, Hawaiian Sugar Planters' Association, Honolulu.

AITKEN, R. T., B. S.,
Anthropologist, Public Museum, Milwaukee.

ANDREWS, E. C., B. A.,
Geologist, Chief Geological Survey, New South Wales.

BAKER, ALBERT S., M. A., B. D., M. D.,

BARBER, EDWARD,
Naturalist.

BARTSCH, PAUL, B. S., M. S., Ph.D.,
Zoolologist, Curator Division Marine Invertebrates, United States National Museum.

BEALS, E. A.
Meteorologist, U. S. Weather Bureau, San Francisco.

BERGMAN, H. F., Ph.D.,
Professor of Botany, University of Hawaii.

BOWIE, WILLIAM, B. S., C. E., M. A., Sc.D.
Hydrographic and Geodetic Engineer, Chief Division of Geodesy, U. S. Coast and Geodetic Survey.

BRIGHAM, W. T., A. M., Sc.D.,
Ethnogolist, Director Emeritus, Bernice Pauahi Bishop Museum, Honolulu.

BROWN, ELIZABETH, Ph. D.,
Research Associate in Botany, Bernice Pauahi Bishop Museum, Honolulu.

BROWN, FOREST B. H., M. S., Ph. D.,
Botanist, Bernice Pauahi Bishop Museum, Honolulu.

BRYAN, WILLIAM ALANSON, B. S.
Zoologist.

BRYAN, EDWIN H., Jr., B. S.
Assistant in Entomology, Bernice Pauahi Bishop Museum, Honolulu.

CAUM, E. L., B. A.,
Assistant Pathologist, Experiment Station Staff, Hawaiian Sugar Planters' Association, Honolulu.

CHAMBERLIN, ROLLIN T., B. S., Ph.D.,
Professor of Geology, University of Chicago.

CHILTON, CHARLES, F. L. S., M. A., Sc.D., M. B., C. M.,
Professor of Biology, Canterbury College, Christchurch, New Zealand.

COTTON, LEO A., M. A., D. Sc.
Professor of Geology, University of Sydney, Australia.

CRAWFORD, DAVID L., M. A.,
Professor of Entomology, University of Hawaii, Honolulu.

CUSHMAN, JOSEPH A., B. S., Ph.D.,
Zoologist, Museum Director Boston Society of Natural History.

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DAINGERFIELD, LAWRENCE H., Ph.D.,
Meteorologist, U. S. Weather Bureau, Honolulu.

DAVIS, GEORGE R.,
Geographer, in Charge Pacific Division, U. S. Geological Survey.

DEAN, ARTHUR L., Ph.D.
President, University of Hawaii, Honolulu.

DILL, H. R.,
Assistant Professor of Biology, University of Iowa.

DILLINGHAM, FRANK T., A. M.,
Professor of Chemistry, University of Hawaii.

DONAGHHO, JOHN S., A. M.,
Professor of Astronomy and Mathematics, University of Hawaii.

EDMONDSON, C. H., Ph.D.,
Professor of Zoology, University of Hawaii.

EHRHORN, E. M.,
Entomologist, Board of Agriculture and Forestry, Honolulu.

EMERSON, JOSEPH S., B. S.,
Ethnologist, President Hawaiian Historical Society, Honolulu.

EMORY, KENNETH, B. S.,
Assistant Ethnologist, Bernice Pauahi Bishop Museum, Honolulu.

EVERMANN, BARTON W., B. S., Ph.D.,
Zoologist, Director California Academy of Sciences, San Francisco.

FISHER, W. J., Ph. D.,
Assistant Professor of Physics, University of Philippines.

FORBES, CHARLES N., B. S.,
Curator of Botany, Bernice Pauahi Bishop Museum, Honolulu.

FOWKE, GERARD,
Archaeologist, Bureau of Ethnology, Smithsonian Institution, Washington, D. C.

FRASER, C. M., M. A., Ph. D.,
Zoologist, Director Biological Station, Nanaimo, British Columbia.

FRYE, T. C., B. S., Ph.D.,
Professor of Botany, University of Washington.

FULLAWAY, D. T., A. M.,
Entomologist, Board of Agriculture and Forestry, Honolulu.

GIFFARD, WALTER M.,
Entomologist, Board of Agriculture and Forestry, Honolulu.

GILDER, W. A.,
Representative of Society for Protection of Native Races, Melbourne, Australia.

GREGORY, HERBERT E., Ph.D.,
Director Bernice Pauahi Bishop Museum, Honolulu; Professor of Geology, Yale University.

GROSVENOR, GILBERT, A. M.,
President National Geographic Society, Editor-in-Chief National Geographic Magazine.

GUERRERO, LEON M., Phar. D.,
Economic Botanist, Philippine Bureau of Science.

HEDLEY, CHARLES,
Zoologist, Curator Australian Museum, Sydney.

HENDERSON, JOHN B., A. B., LL. D.,
Zoologist, Regent U. S. National Museum.

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HENKE, LOUIS A., B. S.,
Agriculturist, Professor of Agriculture, University of Hawaii.

HOLM, ADOLF,
Superintendent of Forest Nurseries, Hawaiian Sugar Planters' Association, Honolulu.

HOVEY, EDMUND OTIS, Ph.D.,
Geologist, Curator American Museum of Natural History, New York.

JAGGAR, T. A., Jr., A. M., Ph.D.
Volcanologist, Director Hawaiian Volcano Observatory, Hawaii.

WOOD-JONES, FREDERICK, M. B., B. S., D. Sc.
Anthropologist, Professor of Anatomy, University of Adelaide.

JUDD, ALBERT F., A. B.,
President, Board of Trustees, Bernice Pauahi Bishop Museum, Honolulu.

JUDD, C. S., M. S.,
Botanist, Superintendent of Forestry, Territory of Hawaii.

KISHINOUYE. K., Sc.D.,
Professor of Fisheries, Tokyo Imperial University, Japan.

KRAEBEL, CHARLES, A. B.,
Assistant Superintendent of Forestry. Territory of Hawaii.

KROEBER, A. L., A. M., Ph.D.,
Professor of Anthropology, University of California.

LITTLEHALES, G. W., C. E.,
Hydrographic Engineer, U. S. Hydrographic Office.

LYON, H. L., Ph.D.,
Botanist in charge Experiment Station Staff, Hawaiian Sugar Planters' Association, Honolulu.

MACCAUGHEY, VAUGHAN, B. S.,
Botanist, Superintendent of Public Instruction, Honolulu.

MASO, REV. FATHER MIGUEL S., D. D., Ph. D.,
Seismologist, Chief Seismic and Magnetic Division, Philippine Weather Bureau.

MAYOR, ALFRED G., M. E., Sc.D.,
Biologist, Director Department Marine Biology, Carnegie Institution.

M'COMB, HAROLD,
Observer, Coast and Geodetic Survey, in charge Honolulu Magnetic Observatory, Ewa, Oahu.

McEWEN, GEORGE F., Ph.D.,
Oceanographer, Scripps Institution for Biological Research of the University of California, La Jolla, California.

MERRILL, ELMER D., B. S., M. S.,
Botanist, Director Philippine Bureau of Science.

MILLER, GERRIT S., Jr., A. B.,
Curator Division of Mammals, U. S. National Museum.

MOORE, H. F., Ph.D.,
Deputy Commissioner, U. S. Bureau of Fisheries.

MORITZSON, A.,
Dunedin, New Zealand.

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MUIR, F.,
Entomologist, Experiment Station Staff, Hawaiian Sugar Planters' Association.

OMORI, FUSAKICHI, Sc.D.,
Professor of Seismology, Tokyo Imperial University, Japan.

OSBORN, H. T.
Assistant Entomologist, Experiment Station Staff, Hawaiian Sugar Planters' Association.

O'TOOLE, GEORGE BARRY, Ph.D.,
Professor of Biology, Seton Hill College, Greensburg, Pa.

PALMER, H. S., A. B.,
Assistant Professor of Geology, University of Hawaii.

PEMBERTON, C. E.,
Assistant Entomologist, Experiment Station Staff, Hawaiian Sugar Planters' Association.

PHILLIPS, STEPHEN, W., A. B.,
Historian, Salem, Mass.

PILSBRY, H. A., B. S., Sc.D.,
Conchologist, Curator Department of Mollusks, Philadelphia Academy of Sciences.

POTTS, CAPT. FRANK,
Zoologist, Fellow Trinity Hall, Balfour Student, Cambridge University, England.

RICHARDS, HENRY CASELLI, Sc.D.,
Professor of Geology, University of Queensland, Australia.

ROMBERG, ARNOLD, Ph.D.,
Seismologist, Professor of Physics, University of Hawaii.

SAFFORD, WILLIAM E., Ph.D.,
Economic Botanist, U. S. Department of Agriculture.

SHIA HSU TAN,
Chinese Consul, Honolulu.

SHIBATA, K., Sc.D.,
Professor of Botany, Tokyo Imperial University, Japan.

SMITH, WARREN D., B. S., M. A., Ph.D.,
Professor of Geology, University of Oregon.

STOKES, J. F. G.,
Ethnologist, Bernice Pauahi Bishop Museum, Honolulu.

SULLIVAN, L. R.. M. A.,
Anthropologist, American Museum of Natural History.

SUSSMILCH, C. A.,
Geographer, Director School of Technology, Newcastle, New South Wales.

SWEZEY, OTTO H., M. S.,
Entomologist, Curator of Entomology, Bernice Pauahi Bishop Museum, Honolulu.

THOMSON, J. ALLAN, M. A., D. Sc.
Geologist, Director Dominion Museum, Wellington, New Zealand.

THRUM, THOMAS G.,
Ethnologist, Editor "Hawaiian Annual" and "Fornander Papers," Honolulu; Associate in Hawaiian Folk Lore, Bernice Pauahi Bishop Museum, Honolulu.

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THURSTON, LORRIN A.,
President Hawaiian Volcano Research Association, Honolulu.

TILDEN, JOSEPHINE E., B. S., M. S.,
Professor of Botany, University of Minnesota.

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I. GENERAL RESOLUTIONS.

1. FUTURE CONFERENCES.

Since the present Conference has been found highly inspiring and illuminating and an invaluable aid in defining the essential problems of the Pacific Region, be it

RESOLVED, That future similar conferences should be held at intervals of not over three years.

2. PERMANENT ORGANIZATION.

The results of the First Pan-Pacific Conference have demonstrated the high value of meetings for the discussion of problems common to all countries whose interests lie wholly or in part within the Pacific area; and have shown that the problems relating to the welfare of Pacific peoples are too large and too complex to be solved satisfactorily except by sympathetic cooperation of individual institutions and governmental agencies. To develop a unity of interest and to make harmonious coordination practicable, it seems desirable that some permanent organization be established which may serve as the point of contact for representatives of various interests in the countries of the Pacific. Be it therefore

RESOLVED, That the attention of the Governor of Hawaii be called to the great opportunity afforded by an organization designed for the advancement of the common interests of the Pacific, including scientific research, and to the desirability of taking action which may lead to the development of such an organization vouched for and supported by the various Pacific countries.

3. INTERNATIONAL RESEARCH COUNCIL.

Since this Conference commends the organization of the International Research Council as a means toward coordinating research in science, be it

RESOLVED, That it is the desire of this Conference that any agency created for the guidance of scientific research and exploration in the Pacific region may be affiliated with the Council and with the various National Research Councils of the nations of the Pacific.

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4. SHIPS FOR EXPLORATION.

The cost of scientific researches in the Pacific which involve the continuous use of a ship is prohibitive for most scientific institutions and individuals. The results of the Challenger and the Wilkes expeditions have demonstrated the great advantage gained by the use of government-owned ships for scientific exploration. Be it therefore

RESOLVED, That the members of this Conference unite in inviting the attention of governments to the desirability of providing vessels for suitably planned expeditions.

5. PROMOTION OF EDUCATION.

The results of scientific research have led to extehsions of human knowledge and to increased control of the forces and resources of nature the values of which cannot be measured. All scientific work which is well done is of value, and no man can predict to what useful purposes the results of any investigation, no matter how recondite, may be put. It is of fundamental importance that sufficient numbers of young men and women of first class ability shall be adequately trained, and that teachers and investigators shall be properly compensated. This Conference therefore

RECOMMENDS:

(a) That in order that young men may enter upon scientific careers without sacrificing all hope of reasonable financial returns, the compensation for instruction and for research in science be increased so that all can at least be assured of a comfortable living for themselves and their families, and that men of exceptional attainments may receive financial rewards which shall approximate those which their powers could command if directed to commercial ends.

(b) That persistent efforts be made to inform the public of the progress of science and of its bearings upon the practical affairs of life.

(c) That to enlarge the experience and vision of the instructors in the colleges and universities of the Pacific countries, making them thereby more competent and inspiring teachers, the exchange of teachers between institutions in different countries be encouraged and made possible.

(d) That a clearing house of information relative to oppor-

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tunities for scientific study and research in the Pacific area be established.

(e) That arrangements be perfected between the universities and other research institutions whereby properly qualified students may move from institution to institution carrying on their work at the place or places where the best facilities are available for the special kind of work upon which each may be engaged.

(f) That a considerable number of fellowships, with adequate stipends, be provided, which shall be looked upon as compensation for the faithful performance of scientific work, and that especially able work by young investigators be rewarded by substantial prizes.

(g) That to stimulate interest in the Pacific and inculcate a knowledge of its importance and unity, text books be prepared in which proper emphasis will be placed upon the Pacific area, its physical features, peoples, fauna, flora, resources, and trade, and that the schools in Pacific countries be encouraged to give instruction which will stimulate the interest and enthusiasm of young students in the objects and phenomena of their environment.

II. ANTHROPOLOGY.

1. NEED FOR POLYNESIAN RESEARCH.

Recognizing the necessity for the immediate prosecution of anthropological research in Polynesia, this Conference calls the attention of governments, patrons of research, and research foundations to this important scientific need, and

RECOMMENDS, That the most prompt and efficient steps be taken to record the data necessary to the understanding of man's development in the Pacific area.

2. FACILITIES FOR INSTRUCTION AND RESEARCH IN ANTHROPOLOGY.

Since there is urgent need both for anthropological research and the training of men and women therefor, and since experience has shown the advantage of close association between the graduate departments of universities and persons and institutions carrying on anthropological investigations, this Conference

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RECOMMENDS, That centers be created for the study of anthropology and original research therein, such centers to be developed by the expansion of university departments or the alliance of universities with other research institutions with the result that these schools of anthropology shall combine all the essential features of a museum, a research staff, and a graduate school. And, further, because of the peculiar conditions under which anthropological data must be gathered, necessitating both intensive field work in circumscribed areas extending over several years, and intensive synthetic work by men who are masters in many fields, thus requiring a number of men through a period of years, we therefore recommend the establishment of research fellowships in Polynesian anthropology, such endowments being provided that these fellowships will attract the best men available and provide for uninterrupted work during an adequate number of years.

3. THE BAYARD DOMINICK EXPEDITION.

It is evident that fuller knowledge of the history and culture of the Polynesian race is essential to the solution of the ethnologic problems of the Pacific; and also that the opportunities for obtaining information are rapidly disappearing. It is therefore gratifying to learn that Mr. Bayard Dominick has conceived a plan for ethnological studies in the Pacific on a scale not hitherto attempted and has provided funds for the initiation of this research under the guidance of Yale University and the Bishop Museum.

RESOLVED, That the commendation of this Conference be extended to Mr. Dominick for his far-sighted interest and generosity and that assurance of good will and cooperation be given him.

SHIPS FOR BAYARD DOMINICK EXPEDITION.

The Bayard Dominick expedition of the Bishop Museum is now in the field and the successful continuation of its work depends upon obtaining a ship suitable for the navigation of waters outside of established trade routes.

The Conference invites attention of the United States Government to the benefits likely to result from providing this expedition with a suitable vessel.

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III. BIOLOGICAL SCIENCE.

1. MARINE BIOLOGICAL SURVEY.

The necessity for conservation of natural resources has become imperative, since, in the case of the Pacific Ocean, certain economic marine species have been exterminated and others are in peril of extinction or grave depletion. Measures for such conservation must be based on an exact knowledge of the life histories of marine organisms. Knowledge of the biological, physical, and chemical phenomena of the Pacific Ocean is meager and wholly inadequate to serve as the basis for rational conservation measures; therefore be it

RESOLVED:

(a) That the First Pan-Pacific Scientific Conference recommends that the governments of the several nations bordering on the Pacific Ocean cooperate, through their several agencies concerned in surveying and charting the sea, toward the collection, compilation and publication of data relating to the topography of the bottom, and the temperature, salinity, acidity, currents, and other physical and chemical properties of the waters of this ocean, fundamental to biological research and the improvement and conservation of the fisheries.

(b) That the Conference recommends that a comprehensive systematic biological survey of the Pacific ocean and its contained islands be undertaken, with special reference to the economic fisheries problems and that the investigation be carried on in so far as possible through existing agencies, such agencies to be provided with the additional apparatus and facilities necessary, the investigation to be carried on under such cooperation as will prevent duplication of effort.

(c) That the Conference recommends that the several museums, biological stations, and other institutions engaged in biological investigations relating to the Pacific ocean, associate themselves for the purpose of exchanging information concerning past, current, and proposed investigations, the exchange of facilities and personnel, the coordination of work, and the prevention of duplication in their respective activities. It is further recommended that a survey be made of the facilities afforded by the several institutions, said survey to cover material, equipment, environment, and the personal qualifications of the respective staffs

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for supplying special information and working up material. It is further recommended that the National Research Council of Washington, D. C., be invited to undertake or arrange for such survey and that a committee of this Conference be appointed to represent the interests of the botanical and zoological sections in this regard, the committee to be appointed by the Chairman of this Conference.

(d) That the Conference recommends that systematic statistics of the fisheries be collected and published annually and that such statistics be, as far as possible, uniform in character and in such detail as to methods of fishing and geographical distribution as to make them useful in fisheries administration and conservation. It is further recommended that the several governments provide for a joint commission for the arrangement of the details of such statistical compilations.

2. RECOMMENDED INVESTIGATIONS IN MARINE BIOLOGY.

Because of the urgency or importance of certain investigations, this Conference

RECOMMENDS:

(a) The collection of bottom samples from depths under 20 fathoms, since these are not usually obtained by deep sea expeditions and can be readily obtained at anchorage by simple apparatus.

(b) The study of the brachiopod faunas above the 1000 fathom line inasmuch as a knowledge of these Brachiopods supplies important evidence on the question of former land connections.

(c) A systematic and thorough study of Pacific Ocean algae and of the conditions under which they occur and of the part they play in their environment; this could be obtained by means already employed for certain parts of the Pacific Ocean and would be of great scientific value.

(d) Because the Hawaiian Islands lie on the margin of the tropical seas, and therefore occupy a critical position for the study of the ecology of marine organisms, among which corals are important; and because data obtained from ecologic investigations in this locality would be of value to geologists in interpreting the conditions under which fossil faunas lived, the Conference recommends a careful study of the ecology of the marine organisms

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of the Hawaiian Islands, and particularly a study of the corals and of the organisms associated with the corals on the reefs.

3. LAND FAUNA.

The part played by living animals in the solution of many scientific problems in the Pacific is well recognized. The relationship of their present to their former areas of distribution and to that of extinct allied forms is the key to some of the geological problems; they have direct bearing upon many ethnological problems and they are the chief source of evidence upon which our ideas of evolution must be built. From a knowledge of the land fauna follow great economic advantages, such as the protection of the human race against many diseases and crops against pests.

Although in certain continental Pacific areas and some of the larger islands the land fauna is fairly well known, yet in none is knowledge yet complete, and in some, such as Polynesia, it is very deficient. The urgency for this work is great, as large areas are rapidly being swept of their native land fauna. Therefore this Conference

RECOMMENDS:

(a) That surveys, as complete as possible, be made of the land fauna, especially of those smaller islands in which the native fauna is fast disappearing, or is likely to become extinct in the near future.

(b) That the attention of zoologists be called to recently made land areas due to volcanic or other activity and the importance of the study of ecological development with special reference to the appearance of animal life upon such areas.

(c) That since land mollusks supply information of value in zoogeographical researches, material for a comparative study of the anatomy of the soft parts of land snails be obtained from all the high islands of Polynesia, Micronesia, and Melanesia, and that adequate faunistic collections be made on islands the faunas of which are not at all or only partially known.

4. ORNITHOLOGICAL SURVEY OF THE PACIFIC.

This Conference expresses its gratification at the fact that arrangements have been made by the American Museum of Natural History for the purpose of undertaking and carrying on a comprehensive and intensive ornithological survey of the islands

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of the Pacific Ocean, particularly those of the South Seas, and extends its thanks to those who have made provision for the expedition.

5. COLLECTING POLYNESIAN LAND FLORA.

Since a definite knowledge of the flora of Polynesia is essential to a proper understanding and correlation of numerous problems bearing on the life and origin of Polynesian peoples, problems of forestry, agriculture, ethnobotany, plant diseases, physiology, and ecology; since the original vegetation of some island groups is rapidly being destroyed; and since botanical exploration of Polynesia has been sporadic and in many regions incomplete, therefore the First Pan-Pacific Scientific Conference

RECOMMENDS:

(a) That botanical exploration of Polynesia be extended as rapidly as possible in order to assemble comprehensive collections with as complete notes as possible covering the scientific and economic aspects of Polynesian botany.

(b) That this work of exploration be carried on by existing agencies, by special botanical expeditions, and by heads of non-botanical expeditions employing and supervising native collectors, whenever feasible, for the collection and preservation of botanical material.

(c) That material be collected in bulk, from ten to fifteen specimens of each species, with the object of distributing duplicate specimens to Pacific institutions and to the larger botanical centers of the world.

6. PLANT ECOLOGY ON LAVA FLOWS.

Since new lava flows and other volcanic ejecta offer fresh terrane for the abode of life, therefore this Conference

RECOMMENDS, That studies be made of the stages of ecological development with special reference to the appearance of forms of plant life on new volcanic deposits following an eruption; and also of plants best suited to the speedy rehabilitation for agricultural uses of regions covered by such volcanic ejecta; and of the resistance of plants to volcanic fumes.

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7. PRESERVATION OF THE HILLEBRAND GARDEN (HONOLULU)

Since the botanical garden of the late Dr. William Hillebrand, author of the "Flora of the Hawaiian Islands," situated in the city of Honolulu, is one of the most remarkable gardens in the world, possessing as it does many unique and rare plants introduced into the Hawaiian Islands by Dr. Hillebrand, and since this Conference believes that the preservation and perpetuation of this garden, which is threatened with destruction, would be a great benefit to botanical science, it recommends that the steps be taken to insure the preservation of this garden.

IV. GEOGRAPHY.

1. TOPOGRAPHIC MAPS.

The exploration of Pacific regions in many branches of science is handicapped by the almost total lack of topographic maps. There is scarcely any human activity which does not depend to a greater or less degree upon a knowledge of the configuration of the land. This is especially true in such work as mining, railroad and highway extension, and maintenance, and the utilization of water in power development, irrigation, and transportation. The natural resources of the world cannot be discovered and utilized efficiently without such maps.

Topographic maps of any given area should be adapted in scales, accuracy and details, to the scientific and economic needs peculiar to the area.

The benefits derived from adequate topographic maps are far greater than their cost and this Conference urges that a plan be made for carrying on a topographic survey of the lands of the Pacific regions, and that this plan be designed to give uniformity of results. This Conference commends the countries of the Pacific region for the work already done by them.

2. SURVEY OF THE SHORELINE AND COASTAL WATERS.

A general hydrographic survey of the continental shelves extending off-shore to the one-thousand fathom curve and of

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the island platforms should be executed, in order to supply basic data essential to all research work involved in the general scientific exploration of the Pacific ocean.

This survey should establish a system of horizontal and vertical control, determine the shore line and adjacent topographic features in true geographic position, develop submarine relief, collect and describe the materials of the bottom, observe temperature and salinity, and define vertical and horizontal movements of the water. The hydrographic bureaus of the nations of the Pacific, as now organized and operating, need only to expand their equipment and extend their field to meet the requirements of this project. Closer cooperation is desirable in the interest of uniformity and to avoid duplication.

These results, in addition to their bearing upon research work, have so great economic value to the shipping, fisheries, and other marine interests that the cost of the survey for the collection of the necessary data is relatively insignificant. It is stated in a recent publication of the United States Coast and Geodetic Survey that the vessels wrecked in the coastal waters of California, Oregon, and Washington in the year 1917 on account of the incompleteness of the charts, involved a loss which amounted to more than double the estimated cost of a complete hydrographic survey of those waters.

This unfinished state of the hydrographic survey along the west coast of the United States is not exceptional; few regions of the Pacific of any considerable extent have been thoroughly surveyed. This Conference makes appreciative acknowledgment of the notable contributions made to the survey of the coastal waters of the Pacific by the several nations bordering thereon; but in view of the magnitude of the work and the length of time involved in its execution it commends this general project and urges its early execution.

3. USE OF WIRELESS TELEGRAPHY IN LONGITUDE DETERMINATION.

This Conference commends the use of wireless telegraphy for the improvement of determination of the longitude of the islands in the Pacific.

4. MAGNETIC SURVEY.

The general magnetic survey of the Pacific ocean should be

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continued to an early conclusion and provision made for such additional work as may be needed to determine annual and secular changes in the magnetic elements. The field of work should be extended to include the coastal waters, where the magnetic phenomena are complex, and their determination essential to many important interests.

Systematic operations under this project are a comparatively recent undertaking; but already excellent results have been obtained in the Pacific from the work of the Carnegie Institution of Washington.

The work is of immediate and vital importance to navigation and surveying, in addition to its bearing upon the general subject of geophysics, and this Conference hopes that plans may be made for a complete magnetic survey of the Pacific region and that the work may be expedited.

5. PHYSICAL OCEANOGRAPHY.

Oceanographic investigations yield results which constitute a basis essential for scientific exploration and research in the Pacific region, notably in meteorology, geology, botany, and biology. Moreover, such investigations are of importance to navigators in disclosing dangers to vessels sailing the ocean and are of economic value in enabling vessels to save time and fuel in their navigation.

The present knowledge of the oceanography of the Pacific is deficient in every branch and constitutes but a meager array of data scattered widely.

In the oceanographic investigation of the Pacific waters the configuration of the bottom should be determined, specimens of the bottom deposits collected and their thickness and stratification revealed, the physical and chemical characteristics of the water at different depths and times determined, and the horizontal and vertical circulation of the waters observed.

The field work involved in such investigations must be carried on almost entirely by the governmental hydrographic organizations of the countries bordering on and contained within the Pacific ocean, owing to the great expense involved in creating new and special agencies, and because the governmental agencies have the personnel trained in this work. Those carrying on oceanographic surveys in the Pacific should avail themselves of the services and advice of individuals and

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organizations dealing with those branches of science depending upon the results of such surveys.

This Conference feels that a systematic oceanographic investigation of the Pacific should be undertaken as soon as possible. The plan adopted should be designed to complete the survey of the most critical areas at an early date, and eventually of the whole Pacific region.

6. METEOROLOGY.

Investigations in meteorology or the physics of the atmosphere designed to lead to an accurate scientific knowledge of atmospheric phenomena are of recognized importance. Very little is known of the behavior of the upper air over the land, and still less over the ocean. The fundamental aspects of these phenomena are exhibited in their simplest manner over the greatest of oceans, the Pacific. Hence it is necessary to make meteorological observations over the Pacific for use in studying the more complex problems over the land.

Moreover, the collection and prompt dissemination of marine meteorological data are of great benefit to humanity in carrying on its commerce and in weather forecasting which is now limited by a lack of synchronized, uniform meteorological data over great areas not within the customary track of vessels.

Observations at the place of origin of typhoons, hurricanes, larger cyclonic and anticyclonic areas, as well as the development, dissipation, oscillation, and translation of the same, are essential to successful forecasting and the study of ocean meteorology. Moreover, the meteorological survey of these ocean areas has practical value. Therefore, the governments of the countries bordering on the Pacific ocean are invited to consider carefully these matters with a view to increasing the number of meteorological vessel and land stations within the confines of this ocean and on its borders, especially the establishment of vessel reporting stations in somewhat fixed positions. In considering these matters, it is believed that special attention should be given to increasing the number of stations in the well known "centers of action."

The First Pan-Pacific Scientific Conference commends the ocean navigation companies and their masters of vessels for the valuable assistance they have rendered the meteorological services

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of several stations and urges them further to cooperate especially in the matter of transmitting their weather reports by radiograph as well as by mail.

7. METEOROLOGICAL STATION ON MACQUARIE ISLAND.

Since the observations made at the meteorological station on Macquarie Island resulted in improvements in the accuracy of weather forecasting, this Conference expresses the hope that observations at that station, interrupted by the war, may be resumed at an early date.

8. METEOROLOGICAL STATION ON MAUNA LOA.

In view of the fact that Mauna Loa, Island of Hawaii, the highest accessible point in the central Pacific, offers exceptional opportunities for the exploration of the upper air, this Conference recommends that a station of the first order be established on its summit for continuous meteorological observations.

9. EARTH TIDES.

The successful operation of the Michelson earth-tide apparatus at a station in the United States of America has furnished data from which the knowledge of the physical characteristics of the interior earth has been increased, and it is desirable that earth tide stations be established in the Pacific region at widely separated points in order to discover whether the physical characteristics vary from place to place.

This Conference hopes this work will be extended.

10. ISOSTATIC INVESTIGATIONS.

Investigations in the theory of isostasy have thrown much light on the subject of deviation from the normal densities in the outer portions of the earth, which is of importance in the study of geology and in other branches of science.

Much can be added to our knowledge of isostasy by a mathematical reduction of existing field data, following well known methods, which would involve only slight expense.

This Conference urges, in the interest of geophysical and other sciences, the early reduction of existing geodetic data

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and the extension of geodetic field work to those regions of the Pacific where such data are now lacking.

This Conference commends the Coast and Geodetic Survey of the United States, the Trigonometric Survey of India, and the Dominion Observatory of Canada for work they have done in isostatic investigations.

V. GEOLOGY.

1. GEOLOGICAL MAPS.

Since it is in the interest of science and of value in the development of the natural resources of the different countries concerned, be it

RESOLVED, That the following maps of the Pacific region on the international scale of 1:1,000,000 be completed as expeditiously as possible:

(a) A base map showing by contours or hachures as many topographic features as practicable.

(b) A map showing geological formations or groups of geological formations.

(c) A map showing mineral resources.

2. GEOLOGICAL SURVEYS OF CRITICAL INSULAR AREAS IN THE PACIFIC OCEAN.

GEOLOGICAL SURVEY OF EASTER ISLAND.

Since a knowledge of the geology of Easter Island might throw light on the question of whether there was in past geological time a westward extension of the land area of the South American continent, be it

RESOLVED, That it is desirable to have a careful study of Easter Island to determine the character and geologic age of the rocks composing that island.

GEOLOGICAL SURVEY OF THE HAWAIIAN ISLANDS.

Since the results of a detailed geological survey of the Hawaiian Islands would aid in the solution of many problems of the Pacific region, be it

RESOLVED, That this Conference strongly recommends

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that a geological survey of the Hawaiian Islands be made and that appropriate geological maps and descriptive texts be published.

GEOLOGICAL SURVEY OF SEVERAL SMALL ISLANDS IN EASTERN FIJI.

Since raised coral atolls with exposed basements of bedded limestone or of volcanic material are found in eastern Fiji, and since a geological survey of these islands supplemented by reconnaissance work in the neighborhood of Suva would be invaluable in the study of the origin of coral reefs, and in the elucidation of the geology of the southwest Pacific, be it

RESOLVED, That a topographic and geological survey of the several small islands, such as Mango, Thithia, Lakemba, Vanua Mbalavu, and Tuvutha be made at the earliest opportunity, and the results published.

3. FORM OF OCEAN BOTTOM.

Because of their importance as supplements to geological work on land in determining the structural framework of the Pacific region and in interpreting the geological history of the region, be it

RESOLVED:

(a) That the configuration of the bottom of the Pacific ocean be determined with adequate accuracy.

(b) That charts of the littoral and sub-littoral zones be made in all practicable detail; for example, wherever possible these charts should be on scales ranging between 1:10,000 and 1:40,000.

4. POST-CRETACEOUS CORRELATION.

Since such knowledge is essential to the establishment of an adequate basis for the stratigraphic correlation of the post-Cretaceous formations of the Pacific region, be it

RESOLVED:

(a) That in addition to the study of the post-Cretaceous stratigraphy and paleontology of the Pacific islands and of the land areas on the margins of the Pacific ocean, such work

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also be expedited in the Caribbean region and in the region from Burma through the Himalayas to the Mediterranean sea.

(b) That inventories of the living fauna and flora of the Pacific region be prepared at the earliest practicable date.

5. STUDIES OF SUBAERIAL AND SUBMARINE EROSION.

Since it is coming to be recognized generally that a knowledge of subaerial and submarine erosion is indispensable to a correct interpretation of the history of the continents, the continental margins, and the oceanic islands during post-Cretaceous time, be it

RESOLVED:

(a) That geologists, geographers, seismologists, biologists, and others who are interested in the facts of form within the Pacific ocean and along its margins devote attention to the study of physiographic processes and the forms resultant from such processes.

(b) That geologists and physiographers make special study of the physical, chemical, and other properties of igneous and sedimentary rocks so as to ascertain the difference in their resistance to erosive agents.

(c) That efforts be made to obtain assistance in furthering the study of wave and current erosion, the factors limiting wave base, the action of weathering and corrosive agents at the headwaters of streams, the forms of stream channels, the form of sea cliffs at different stages of development, the action of plants in retarding land erosion, and the sequential stages of erosion of fault scarps.

6. STUDIES OF SEDIMENTARY PROCESSES AND SEDIMENTARY ROCKS.

Since it is generally recognized that the interpretation of a large part of the geological record demands a knowledge of the processes of sedimentation and the results of these processes in the formation of deposits of past geological time, therefore be it

RESOLVED:

(a) That geologists, oceanographers, geographers, biolo-

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gists, and others who may be interested devote as much attention as possible to the study of modern sediments and the processes by which they are formed.

(b) That geologists make special studies of the physical, chemical, and other properties of sedimentary rocks to ascertain the conditions under which the deposits were formed and the changes that may have taken place in such sedimentary rocks after deposition.

(c) That all existing agencies be urged to study the phenomena referred to in paragraphs (a) and (b) above, and that efforts be made to increase the number of agencies for the prosecution of such investigations.

6. GEOLOGICAL COOPERATION.

Since it is desirable that the projects undertaken by the different workers in the Pacific region be so selected and so designed that each may be supplementary to the rest and so contribute to the uniform accumulation of geological information concerning the Pacific region, be it

RESOLVED, That steps be taken to advise in the planning of research, to correlate the efforts of the different workers, and to promote in such ways as may be proper a uniform mode of publication of results.

VI. SEISMOLOGY AND VOLCANOLOGY.

The dominant motive which has appeared in the convention of seismologists and volcanologists of the Pacific here gathered together for the first time, has been to promote more localized and more continuous observation of regional phenomena than has hitherto been accomplished in most seismic and volcanic districts. On the other hand, there is agreement that precise teleseismic triangulation is not a field for amateurs or for stations equipped with a multiplicity of inferior and diverse instruments.

There is urgent need for mutual information, regularly supplied by each observer to his distant colleagues, concerning volcanic and seismic happenings in each land. The employment of mariners and scientific expeditions to collect specimens and notes for the volcanologists in remote places may be organized.

Education of the people in matters of earthquake-proof con-

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struction and safeguards against disaster has been proved to be a practicable and effective method of meeting volcanic and seismic crises.

Interest has recently developed in the earth tide, changes of level about volcanoes, and measurable horizontal and vertical displacements directly related to earthquakes. These are matters for the national geodetic surveys and for geophysical investigation of high mathematical precision.

The consideration of the needs indicated above, namely, localized work, distribution of information among workers in this field, education of the people at large, and the applications of precise geophysics has led to the following resolutions:

1. ESTABLISHMENT OF VOLCANO OBSERVATORIES.

Useful volcano experiment stations have already been established in some lands, and more volcanologic experience is needed for protection against disaster of the increasing populations of Pacific countries and for the advance of science; therefore this Conference

RECOMMENDS the continuance of the present volcano observatories and the establishment of new permanent volcano observatories in lands about the Pacific; and recommends that such a station for maintenance and publication of continuous observations should be placed on one or more active volcanoes in each important volcanic district.

2. PROMOTION OF LOCALIZED SEISMOMETRY.

In addition to the work of existing establishments, the intensive study of both large and small earthquakes in seismic provinces by all appropriate physical, geological and other scientific methods may lead to important and rapid advancement in geophysical knowledge. This knowledge is of importance for economic and humanitarian as well as scientific ends. This Conference therefore

COMMENDS the existing institutions, recommends their continuance and expansion, and urges early establishment of further specific programs of investigation and continuous observation in regional seismology in special seismic districts about the Pacific. Timely publication of results is recommended. Moreover this conference recommends to the National Research Council of the United States the establishment of a pro-

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gram of research in regional seismology in the southwestern part of the United States.

3. PUBLICATION OF VOLCANO AND EARTHQUAKE INFORMATION.

The workers in regional seismology and volcanology need accurate information about geophysical events in other localities than their own; therefore this Conference

RECOMMENDS, That prompt and authoritative publication of current facts and measurements concerning volcanoes, earthquakes, submarine eruptions, and tidal waves be an essential part of the routine of all Pacific observatories.

4. PRECISE LEVELING AND TRIANGULATION IN RELATION TO VOLCANOLOGY AND SEISMOLOGY.

Great earthquakes and volcanic eruptions are often preceded and followed by elevations, depressions, and horizontal displacements in the regions concerned; therefore this Conference

RECOMMENDS, That precise leveling and triangulation be carried on at definite time intervals, in selected seismic and volcanic districts, in order to ascertain precursory and other changes in underground stress accompanying great seismic and volcanic disturbances.

5. COLLECTION AND PUBLICATION OF STATISTICS OF EARTHQUAKES AND ERUPTIONS.

There is needed for certain Pacific countries more complete statistics concerning earthquakes and eruptions; and a complete list for the world should eventually be maintained; therefore this Conference

RECOMMENDS, That each Pacific country publish statistical lists of local eruptions, earthquakes, tidal waves, and other related phenomena; and issue catalogues of active, dormant and extinct volcanoes, and of local seismic features.

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6. CENTRAL SCIENTIFIC BUREAU.

Dissemination of volcanologic and seismologic knowledge will be furthered by working through a body cooperating with all Pacific countries; therefore this Conference

RECOMMENDS the establishment of a central bureau for dissemination of scientific knowledge among the volcano and earthquake stations of the Pacific.

7. SAMOAN GEOPHYSICAL STATION.

This Conference COMMENDS highly the work done at the Geophysical Observatory at Apia, Samoa, and expresses the hope that the service of that station will be continued.

8. EDUCATION OF DWELLERS IN DISTRICTS LIABLE TO DISASTER.

Great injury and loss of life to persons and damage to human constructions may be caused by earthquakes and volcanic eruptions and may be decreased by general education; therefore this Conference

RECOMMENDS, That countries liable to seismic disaster educate the people in proper methods of construction, in behavior during emergencies, and in the history of such catastrophes elsewhere.

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PAPERS PRESENTED
DISCUSSIONS
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RACE RELATIONS IN THE PACIFIC

INTRODUCTORY REMARKS

By F. Wood-Jones, Herbert E. Gregory, Alfred G. Mayor and A. F. Judd

Mr. F. Wood-Jones, Chairman of the Session: There are some subjects which are on the same footing as those industries which we have learned in recent years to term "key industries." We must all acknowledge, of course, that whatever our opinions with regard to the Pacific, we must all in the end bow to the geologists. They have the key subject in the solution of problems in the Pacific. Looked at from that point of view, anthropology is apparently unimportant. There is very little, one thinks at first sight, which anthropology can solve or hope to solve. I am sure some of you yesterday must have been struck by the findings of Dr. Pilsbry when he demonstrated how apparently the land shells had come into this great Pacific world from the west toward the east. Very soon after we were told that vegetation had come in from the east toward the west, thus dealing with two utterly different groups, and two utterly different methods of dispersal. In Dr. Mayor's opinion it is quite possible that man has been responsible for the spread of economic plants and animals from west to east. For anthropologists this Conference will close, I am quite certain, with the feeling that we know extraordinarily little of the problems with which we are supposed to deal. Our knowledge of the distribution of man and his wanderings in spite of the enormous amount of work done is extremely vague. Our knowledge is extremely scattered at best. We do not occupy the position of a key science. If we knew more of the comings and goings of man in the Pacific we could trace much better that very earliest type of sailor who has been navigating the Pacific for a thousand years; and we should be much more in a position to dictate to the zoölogist and botanist if we knew what sort of cargo he carried, which way he came and which way he went. We could tell you a good deal you are telling us. It is because our knowledge is so scattered that we need to get right to work. All of you geologists and botanists are dealing with permanent features which you can go

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back to at any time and study. The days are numbered in which anthropological studies can be made. From the point of view of this Conference anthropology is one of the very first subjects which should be taken care of. Ever since I have been in Australia I have been trying to urge on scientific bodies that if they are going to study these problems they must study them now because there are so few days left in which to study.

It is exactly the same with the culture and physical anthropology of Polynesia. If we are going to do this as an outcome of this Conference I would ask all interested in anthropology that your first plan should be a proper study of races from the physical and cultural points of view.

This point of view is held I believe by the Bishop Museum and I would ask the Director of the Museum, Professor Gregory, to supplement my remarks.

MR. GREGORY: The statement of your chairman that anthropological and ethnological research is an urgent problem as compared with certain others is at the base of the plans of the Bishop Museum. Fortunately the Museum is unrestricted in its plans for the study of Polynesian ethnology and natural history, and problems may be chosen with reference to their urgency or with reference to their bearing on other problems. The activity which calls loudest for immediate attention is the study of vanishing races, and primarily some groups of the Polynesians.

The much desired researches in geology and botany can scarcely be classed as urgent and the marine fauna will probably be here for centuries, but if the history of the Polynesian race is to be more than a collection of expanded notes, it must be written during this generation. The natural net decrease in the population is speeded up by epidemics. During the past two years influenza has wiped out about one-fourth of the population of British Samoa and of Tahiti and the Marquesans seem to be marked for extinction. The late William Churchill mentioned three Pacific Islands in which the last inhabitant disappeared in 1919—no word of their dialect will ever again be heard. The death of old men and women familiar with tribal customs and traditions is removing the source of information. Professor Crampton recently told me of three old men in Tahiti, talented men whom he had intimately known for a number of years. In his opinion if these three men have been swept away by the

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influenza epidemic the possibilities of effective ethnological study in Tahiti will have declined 50 per cent.

Under these circumstances it is fortunate that the Museum is able during the present year to emphasize anthropological research. A gift to Yale University of $40,000 for studies of the Polynesian people opened the way for intensive work. With the approval of the donor, Mr. Bayard Dominick of New York, this fund was transferred by Yale University to Bishop Museum in the belief that the Museum was in an exceptionally favorable position to utilize this generous contribution. Plans have been formulated with great care in consultation with Dr. Wissler, Professor Dixon, Professor Kroeber and William Churchill. Parties consisting of an ethnologist and an archeologist are now in the Marquesas Islands and in Tonga; a third party is to leave soon for the Austral Island group, and in Hawaii a comprehensive study of physical anthropology is in progress. With each expedition a botanist is being sent, for the simple reason that the story of the migration of the Polynesian race may have to be read in terms of the origin and distribution of food, medicinal and ceremonial plants.

The Museum hopes to be in a position to carry on these investigations for a series of years, but with no idea of preëmpting the field. The Museum is doing this work because it needs to be done and because it is equipped to make a contribution at this time. Other institutions will find Polynesia a fertile field for study. I have no doubt that effective coöperation can be established and I am not much worried about funds; the chief obstructions in the path are the lack of a comprehensive and workable plan and the dearth of trained investigators. I believe this Conference can supply the plan but I don't know where the workers are to be obtained. Mr. Chairman, you may rely on the Bishop Museum to lead or follow, ride tandem or abreast, with other institutions interested in making an immediate attack on the large and complex problem of race relations in the Pacific.

MR. MAYOR: I think we should all congratulate ourselves and the Bishop Museum in having such a broad-minded man as Dr. Gregory. Research in these days is largely a matter of efficient coöperation. The spirit which the Bishop Museum has displayed in this matter in acting as an agent or clearing house for the whole world is most admirable. There is no question

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that it is only by such methods and by giving a fair chance to agencies properly equipped to do specific things that the work can be carried on. For the first time in my life I feel that matters of fundamental import in the anthropology of the Pacific are about to be solved. It is very late to start. Nevertheless, although many pages of the story have long since been torn out or lost, enough remains to provide material for a very interesting volume.

MR. A. F. JUDD: May I emphasize a point made by Dr. Gregory that there is a tremendous need for men? I would like also to venture the hope that the committee on resolutions will pass on in suitable strong wording a memorandum on this subject which should be called to the attention of the Bureau of Education in Washington. Interested as I am in education in Hawaii, being connected with two schools, I find the great difficulty in teaching geography is in getting teachers who know anything about the country. There are plenty of teachers who can teach admirably the boundaries of the State of Wyoming, but they are not familiar with the Pacific Ocean. Neither are we able to purchase proper wall maps of the Pacific; they seem not to exist. I believe every school room in this territory should have such maps, and they should be in every normal school on the mainland and in every school of the countries bordering the Pacific both north and south of the equator.

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MAN IN THE PACIFIC

By Clark Wissler

The topic before us today is "Man in the Pacific." It is not exactly a racial problem as that problem is conceived in popular thought, where it is restricted to certain specific economic and social problems. Our interest is a broader one, but centers in the man of prehistoric time. Yet since historic time in the Pacific scarcely begins before 1750, we may almost ignore this modern fragment which the historian claims as his special province. However, we cannot ignore one of the problems the events of this single historic century have created and one which the historian cannot, or does not, solve; viz., the problem of race mixture.

Anthropologists are well aware that race mixture is not a modern phenomenon. One of the distinguishing characteristics of man, in contrast to other mammals, is his tendency to cross; the only close parallel we have is among certain species of canines—particularly among the dogs. Curiously enough, the history of the dog is intimately associated with man from earliest paleolithic time and is just as difficult to untangle as man's own zoölogical history. I have frequently urged zoölogists to take up the dog, but they always tell me that the problem is too complex. But there is no reason to believe that it is more complex than the human problem, where crossing has gone on for ages. Yet in some parts of the Pacific we have race mixture on an extensive scale and for once the phenomenon can be accurately observed. Hence, regardless of any social or political interest, race mixture should be one of the problems to come before this congress.

We turn now to the prehistoric, or main part of our problem. Primarily this rests in the Polynesians. A great deal of random information has been recorded, bearing upon the numbers, behavior (culture) and appearance of the many insular groups. The mere mass of this data is at first a bit disconcerting, but nevertheless, it is totally inadequate to the problem as we see it today. It is not my intention to burden you with a summary of the available data; but rather to remind you of certain fundamental points of view growing out of the research experience of contemporary anthropologists and to suggest that

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leads these viewpoints indicate for those who take up specific projects in Polynesia.

In the first place anthropological research in Polynesia seeks an answer to each of three questions: (1) Whence came the Polynesian? (2) What are the hereditary strains in his blood? (3) What are the essentials of his history in the Pacific? In other words tell us the origin, blood and chronology of Polynesia—*whence, what* and *when!* There is no difficulty in the formulation of this problem and there is nothing vague in its statement. The plain every-day man can grasp its import without effort. Yet in this beautiful simplicity lies a real danger; for such simple and direct statements often lead one to expect ready and positive solutions. If anyone sets out with the expectation of a ready and clear-cut solution to these questions as the result of a single explorative drive, then it needs no prophet to predict something in the way of disappointment. The ultimate solution of the Polynesian problem will tax to the utmost the research ingenuity of science and will demand the long and persistent labor of two or three of the best scientific minds, capable of synthetizing the results of many sciences.

One of the misfortunes of anthropology is that it looks so easy that anyone backed by a little enthusiasm is tempted to roll up his sleeves and go to it. No doubt this is partly because it is a human problem, but also because the technique and methods of the anthropological investigator are not formulated under a new and high-sounding terminology. For example if a gardener, who dearly loves plants, takes it into his head to be a botanist, the first man he meets knocks all the conceit out of him by reciting a few phrases from the descriptive terminology of the subject. Even my fellow scientists, zoölogists, geologists, etc., often fail to see that anthropology has well developed methods and technique for dealing with all the usual phenomena one meets in exploration. In this discussion, therefore, we can ignore all questions of technical details, taking them for granted just as we do in the case of botany, geology, etc. On the other hand the tendency to underestimate the complexity of anthropological phenomena is so universal, that we can well afford to give some attention to the fundamental viewpoints of the anthropology of today and consider their bearing upon the projected Polynesian research, the consideration of which is before this congress.

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One of the primary objectives in an anthropological undertaking of this kind is, the establishment of a chronology. Those of you who are familiar with the great achievements in Egypt and western Europe, need not be reminded that the chronologies for the two areas are the very foundation stones of the anthropology of today. In the case of western Europe, we have now one great sequence of cultures, or civilizations, beginning with the earliest known stone age and passing on up through the bronze and early iron ages, finally connecting with historic time in which we have recorded dates. One can now say with confidence that the answer to the *when* for western Europe can be given with fair precision and a reliable outline of the chief events in man's career in that part of the world can be given in sequence, showing the time relations between such events as the use of fire, the working of iron and the invention of a steam engine. In short for one small corner of the world we know the outline of the whole story from the first to this very hour. That is no mean achievement and furnishes us the ideal for anthropological research in other parts of the world, to which the Polynesian area is no exception.

There are two main methods of attaining a chronology for man. By man we mean a creature with some kind of a culture; before man began to use tools the chronological methods of zoölogy and palaeontology will suffice; but when we come to deal with a creature who uses tools and who has ideas and communicates them, some specialization in method is necessary.

One of these special methods is that of super-position, or stratification, which literally takes a leaf from the note-book of the geologist. The archaeological method, it is sometimes called, though that term has a much wider application. The point of view in this method of super-position is that undisturbed strata are of necessity formed in the order of their position—the older at the bottom, etc. The stratification of culture remains is, however, man made, in contrast to geological stratification, the different strata representing sequential periods in man's history. From these sequences we get relative time relations, but for the dating of these, anthropology must ultimately appeal to geology, either directly or indirectly, through the fauna and flora involved.

Turning now to Polynesia, we see the necessity for the application of stratification methods in order that a chronology may be realized. Parts of each island must be dissected, as it

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were, to determine the strata of human occupation and culture. We can be reasonably certain for example that the shell heaps of New Zealand contain the story of man in that island and perhaps the general outline of Polynesian chronology as a whole. Likewise these islands, though so far no definite refuse deposits have been located here, contain ruins, caves and town sites, from the proper study of which a chronology may be constructed. These problems of chronology are complex and difficult, but not insuperable. So far this fundamental method has not been applied to any part of the Polynesian area. The secret of success, however, is the man behind the spade; put a keen scientific mind behind the project and results will come. A real intellect and a single section of a large shell heap will open up a new vista in Polynesian research.

We should not forget, however, that the assistance of other sciences will be needed to solve this problem of chronology. First, we need a geological survey of the several island groups; for as we have stated, the backbone of man's chronology is geological chronology. Further, we need data upon the fauna and flora of the respective islands. It is the realization of this inter-relation of problems that underlies the conception of this congress and is its only excuse for being. You tell us the history (a relative chronology) of such plants as taro, bread-fruit, the paper mulberry, etc., and the story of such mammals as the pig, chicken and dog in the islands of the Pacific and we will soon fill in the gaps in the chronological scheme for the Polynesians.

So far we have considered only the man of the past as he survives in skeletal remains and the refuse of culture; but anthropology is not entirely a matter of the paleontology of civilization, it is also called upon to deal with living men and cultures whose antecedents lie far back in the past. How can the chronology of these be attained? For example which is older in Polynesia, the *Kapu* system or the *aawa drinking* complex? In such cases we generally fall back upon distribution. Zoölogists and botanists also use this method; they have by its use discovered the centers of dispersal for many forms and their chronological relations. Anyway anthropologists find that culture complexes are distributed in geographical areas and that the more primitive forms frequently survive in the margins of the areas. The same is true of the anatomical types of man.

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The most primitive men survive, when they survive at all, on places like Tasmania, the southern tip of South America, South Africa, etc. Their positions in the whole distribution of mankind mark them as among the older forms.

By way of illustration, we may cite a more specific and unusual example of the interpretation of distribution in terms of chronology. You are aware that the Spanish explorers found in Mexico and Peru and at intermediate points, very complex cultures like those of the Aztec and the Inca. The area of distribution for these higher cultures is in general terms from the southern boundary of the United States to the northern bounds of Chile.

Now, in the United States a peculiar type of pottery is found north of Mexico, and again south of Peru we have pottery strikingly similar. In western United States we find a curious frame for holding a baby and for carrying it upon the back of the mother; among some of the tribes of Chile and Argentine we find the same form of baby carrier. Then a curious kind of wooden hitch was used in belt looms, both in Argentine and south-western United States. Again, on both the north and the south margins, the natives had the custom of chopping off one or more fingers as a sacrifice to the sun in compliance with conventional vows made in times of great personal danger. Other correspondences could be added to this list, but these will serve as an illustration.

Now, what is the significance of this? Are we not justified in concluding that we have here on the two margins of this great culture area of the New World, the remnants of an older form of culture that once covered the whole intervening area? And are we not justified in concluding that this belongs near the bottom of our chronological scale? In other words by the study of distribution in great detail we can at least infer chronology.

Now, when we turn to Polynesia, we meet with an insular distribution, but in the main the same methods will apply. Never to my knowledge has this method been applied to Polynesia except in the most general way, chiefly because the data are not yet adequate. Yet one or two tentative illustrations may suffice.

The domestication of the south Asiatic fowl, or chicken, was known to the Polynesians. The center of origin for the domestication of the chicken is placed in south Asia, the home of

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the wild species. It spreads westward to Persia, thence to Egypt, down into Africa and over into Europe. East of Asia the chicken spread to the Malay islands and into Polynesia, even to Easter Island, but failed to reach America.

From Egyptian researches we know that the chicken reached Egypt about 700 B. C. From Egypt it spread to the negro tribes of the Congo in Africa where the date of its appearance is placed at 400 B. C. For the introduction of the chicken into the Malay area we have not satisfactory data and likewise for Polynesia: but Egypt and Polynesia are both marginal to the center of dispersion. We may expect, therefore, that the appearance of the chicken in Polynesia can not be much earlier than 1000 B. C. and in all probability much later.

Another interesting culture complex is the making of paper cloth, or tapa as it is called. The materials used are from the paper mulberry, introduced from Asia. In the tapa complex, are printing from wood blocks, the making of lint for the dressing of wounds and the use of a paper kite. In old China paper was made from the same plant by a similar process, and printing from wood blocks was known, also lint for wounds and the paper kite. How completely the paper complex of old China and Polynesia will correspond we cannot yet say for lack of data, but here is a good problem. Most of these processes can be dated in China and to these the parallel processes for Polynesia can be related. One of the first steps, however, is a study of the plants furnishing the materials—the botanists must come to our aid here. When all the returns are in, the relative time of the appearance of the tapa complex in Polynesia can be stated.

While it is true that a great deal of work remains to be done before the origin of the Polynesian can be stated, nevertheless we can forecast his chronology with sufficient precision to project the problem. In the main we find the Polynesian race marginal to the Malay-Asiatic area. There is little in the geological setting to prevent him being also marginal to America, but the parallels to America are so vague that their existence is still in the controversal stage. On the other hand we can be certain that anthropologically Polynesia is primarily marginal to the Malay-Asiatic center. Hence, the problem of the Polynesian is a part of the Micronesian problem, the Melanesian problem, the Malay-Philippine problem, and finally a part of the Asiatic

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problem. It is clear then that the ultimate solution of the Polynesian problem demands intensive work in each of these areas and must in consequence be approached as an international project in the coordination of research.

Another important point is, that as compared with Western Europe, the arrival of the Polynesian is a recent event. Polynesian chronologies have been proposed by Churchhill, Percy Smith, et al. As previously stated these must be taken as very tentative, owing to lack of check data. Yet strange to say all of these estimates place the Polynesian arrival at near 2000 years ago.

Churchill's chronology may be taken as the type.

A. First Proto-Polynesian migration.....A. D. 0
B. Tonga-Fiji migration 600
C. Great Polynesian expansion 1,000

This chronology is based upon linguistic and culture data, but has not been handled by the most advanced methods. It has, however, so great a consistency with the data at hand that we may accept it as a working basis.

As to whether the Polynesian was preceded by a different race, is still too uncertain to be discussed here. It can be formulated only as a problem. Shell deposits, if they exist in sufficient number, may answer this question, but it is useless to speculate as to what the result will be.

In this discussion I have touched lightly upon the racial affinities of the Polynesian and upon the modern question of race mixture, as these topics will be presented by other members of the congress. I have tried to give you a glimpse of the point of view of the anthropologist and to show you that our problem deals both with the living and the extinct, and that because of man's peculiarities, we must consider his functional history as well as his morphology; the data of one will in the end supplement the other; that what we seek in Polynesia is to interpret man's distribution in terms of time and space, as the outline for the investigation of his evolution.

Finally I beg to remind you that the fauna of our subject is on the verge of extinction. The rocks at the bottom of the sea will remain, but the old Polynesian is passing the last mile post of his career. Hence, if anything is to be done with the Polynesian problem, it must be done now.

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DISCUSSION

MR. MAYOR: When we consider the manner of life of Polynesians we see that in fundamental things the Japanese and Polynesians are remarkably alike. Their mental attitude, religious concepts, manners, habits, etc., are so similar that they cannot be due to outside influence but must be due to blood relationship far distant. It is too complex to be a mere matter of accidental resemblance. The whole mental attitude of the Polynesians is so different from the mild code of the Puritans which now dominates the world that they will not tell us their myths and traditions. These stories they know will shock us. Consequently they can only be secured as a reward of the greatest possible patience and tact; perhaps women may achieve greater success than men in such a quest.

MR. SAFFORD: The theory which has sometimes been advanced that the Polynesians came from the East is absurd. Their principal economic plants are of Asiatic origin, and have been carried to Polynesia with their Asiatic, or more strictly speaking their Malayan names. In addition to the coconut, sugar cane, pandanus, hau, milo (*Thespesia populnea*) and noni (*Morinda citrifolia*), may be cited. Sugar cane, called *to* in southern Polynesia and *ko* by the modern Hawaiians, is called *topo* or *tupu* in Guam and *tubu* in the Malay Archipelago. The well known hau tree of these islands (*Hibiscus tiliaceus*) from the inner bark of which the Polynesians made cordage and strainers for their 'ava, and whose light wood was used not only for the outriggers of canoes but also for making fire, is called *fau* in Samoa; and this name can be traced through *pau* to *pagu*, *pago*, and *bago*, to its Philippine name *balibago*. Some of the plant names of Hawaii reappear in New Zealand where they are applied to species of the same genus or to plants having a similar appearance or habit of growth. As an example the bastard sandalwoods belonging to the genus Myoporum may be cited. In both the Hawaiian Islands and New Zealand their vernacular name is *naio*. On the other hand species of Metrosideros, belonging to the same genus as the beloved *ohia lehua* of the Hawaiians have a very distinct vernacular name in New Zealand. It would thus appear that before their separation the common ancestors of the Hawaiians and the New Zealanders dwelt in a locality where species of Myoporum grew but from which Metrosideros was absent.

From plant names and also from the names of fishes, birds, and other animals a fauna and flora of the ancestral home of the Polynesians could be compiled. Numerous examples can be cited as striking as that of *hala* and *fala*, applied in Hawaii and Samoa to species of Pandanus or screw pines. The same principle applies to the names of nearly all natural objects, such as sky, sun, moon, star, sea, ocean, water, stone, bird, fish, seaweed, also to the word for fire, *ahi* in Hawaii and *afi* in Samoa, and *aki* in modern Malayan. The numeral system and many grammatical forms of the Hawaiians and Samoans have been brought from Malaysia.

MR. WOOD-JONES, Chairman of the Session: Dr. Hedley, I believe, has evidence which leads to a different conclusion.

MR. HEDLEY: When a historian wishes to trace the progress of some vanished race, he will ask for documentary evidence, some carving or writing or pottery. I have no evidence to offer except soft herbs, and grasses which may have been where they now are before the human race appeared and may be there when all our race has vanished. The Swedish botanist, De Candolle, wrote many years ago, an account of the

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history of the coconut palm which he declared was essential to the human race in this part of the world. In summing up he presented two alternatives: one was that the coconut palm originated in South America, and the other that it came from Asia and Ceylon. The chief argument in favor of American origin is that there are two hundred species and twenty genera, all of which are related to the coconut palm which comes from this part of the world. There are no coconut relatives on the other side, and if you believe in Candolle's hypothesis of descent with modification, that evidence alone would incline you to believe that the coconut came from South America. On the other hand there is documentary evidence to the effect that the king of Ceylon cultivated and grew the coconut palm three thousand years ago. De Candolle, who was not an ethnologist, was confronted with the difficulty that there were no means of transporting the coconut from America to Asia three thousand years ago. He did not know that the finest race of navigators which the world had then seen were the Polynesians. Here were a people who were capable of transporting the coconut from one side of the Pacific to the other a thousand years before Magellan. If you were to find a very desolate island on which man had never lived, you would find no coconuts. No wild coconut has ever been found by botanical explorers. The coconuts have been tended by human hands and like all cultivated plants would wither and disappear without attention. They are as dependent upon human care as a canary.

Australia from Torres Straits down the coast for a thousand miles is as well suited to support dense coconut groves as is Polynesia, Melanesia and New Guinea, yet along this stretch not one is to be found, while on the opposite shores of New Guinea, Solomon Islands and the New Hebrides, there are dense forests of coconuts. According to the poetic explanation, that coconuts drift over sea and establish themselves on the beach without the aid of man, these beautiful groves should have drifted from island to island. The coconut is not the only evidence. The sweet potato is a native of South America and Captain Cook found it cultivated all over the South Sea Islands.

MR. SAFFORD: I have assisted in opening two hundred prehistoric graves on the coast of Peru and Chili. In these graves were receptacles of all kinds including gourds and imitations of gourds in pottery. There were also many other kinds of fruits and vegetables imitated, but neither I nor any other explorer has found a fragment of a coconut shell nor the representation of a coconut in the prehistoric graves of Peru or of any other part of America. It is very strange that the coconut, if it really grew in prehistoric America, should await the arrival of Columbus before it began to disseminate itself. It is also remarkable that there is not one native American name for coconut; while in many parts of Polynesia and the East Indies there are not only general names for the coconut itself but for innumerable varieties of it, some of them prized for the excellence of the kernel, others for the enclosed water which is used as a beverage, others for the fiber of the husk, etc. On the Pacific coast of Mexico, in the vicinity of Acapulco and farther north, the sap derived from the immature inflorescence is made into a fermented drink, called by the Philippine name *tuba*. Those who write of the history of the coconut usually begin with the first appearance in literature of the name *coco*. As a matter of fact its early name was *nux indica*, and it was under this name that Marco Polo described it before the discovery of America, telling of the important part it played in the economy of certain tribes in the East Indies. Another significant fact is the presence on oceanic islands where the

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coconut grows of the coconut crab, *Birgus latro*, which does not occur in America. Undoubtedly the coconut has been widely spread through human agency. In Polynesia it has taken with it its Malayan name *niu*. That it can establish itself without man's aid has recently been demonstrated in the exploration of Palmyra Island. As Beccari and others have stated it is especially adapted for floating and thus for being disseminated by ocean currents.

An example of the way a coconut can find its way to a new island through human agency is offered in the narrative of one of the early exploring expeditions. A native of the Caroline Islands who had been shipped as one of the crew went ashore on one of the Aleutian Islands. After a short time he got into a boat and returned to the ship. On being questioned he replied: "I come for coconut to plant ashore: these poor people no got coconuts; how can they live?"

The chief argument advanced for the American origin of the coconut is that its nearest relatives are American. It now appears that the so-called cocos palms of South America do not really belong to the genus Cocos, and that its nearest relative is an African palm.

MR. MUIR: Insects have exerted a large influence on race migration. The Arab migration in Africa may be cited as an example. It has been observed that the Arabs spread southward to the border of the belt occupied by the Toltse fly, but not beyond. It is probable that Arabian culture would have spread entirely over the continent of Africa, but for the bar established by the fly.

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THE STATUS OF PHYSICAL ANTHROPOLOGY IN POLYNESIA

By Louis R. Sullivan

It is an easy task to define the status of somatological research in Polynesia. In all fairness to those who have worked in this part of the world, it may still be said that this is a virgin field. Disregarding the scanty data contributed by enthusiastic but in many cases untrained observers, the serious contributions to physical problems in Polynesia may be enumerated in a very limited space. Davis (1867),[1] Flower (1897) and Turner (1884, 1885) in their catalogues have described a few crania from Polynesia. Allen (1898) has described a fairly large collection from Hawaii, and Poll (1904) a series of skeletal remains from the Chatham Islands. Ten Kate (1915, 1916) has measured a few Polynesian natives. We have the unpublished work on the living Hawaiians by Von Luschan and Tozzer. Considering the area of Polynesia and the number of people inhabiting it, the data is entirely inadequate for conclusions as to the racial or inter-insular affinities of the Polynesians from a physical standpoint. As a matter of fact, the various observers enumerated above have appreciated the meagerness of their data and have carefully refrained from drawing any such conclusions or elaborating any theories of origin or migrations. They have been content to stop with descriptions more or less detailed as their interests dictated.

But does that mean that there is a poverty of theories and speculations as to the relationships and migrations of the Polynesians? No, indeed. Probably the history of no other similar group of mankind has been so much speculated upon and so maltreated as has that of the Polynesians. Voyagers, missionaries, legislators and students of all subjects who have traveled in Polynesia or have talked with some one who has traveled in Polynesia, or who have seen photographs of the natives, have been generous in their contributions to the theories and speculations in vogue; nor have they been backward in adding new theories of their own manufacture. In the literature it is easy to find authority for including or excluding the Polynesians in or from all the races of mankind. They have been grown here, or brought here from America, Northern Asia, India, Africa and even northwestern Europe by various authorities.

[1] A bibliography is published at the end of this paper.

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In order that I may not seem to exaggerate, let me be more specific in my statements. Lesson regards the Polynesians as autocthones, originating in South Island of New Zealand, which he thinks is the Hawaiki of tradition. Fornander (1870) says they came from Saba, Arabia by way of India and are a branch of the great Indo-European family. Fenton (1885), Gill (1876), Tregear (1904) and Gudgeon (1885) follow Fornander with trifling qualifications and reservations. Ellis (1829) says they came from the West. He later suggests that they first crossed the Pacific to America and then returned to Polynesia. Brown (1920) suggests two migrations, one by way of Europe, northern Asia and the Philippines and a sceond by way of India.

So much for speculations as to the origin and migrations of the Polynesians. The solution of these two problems will always remain more or less speculative. It is certain that physical anthropology can not offer the solution. Nor, I believe, can any of the other branches of anthropology alone. It is only after extensive study of the physical anthropology, archaeology, linguistics, ethnology, ethnobotany and ethnozoölogy of the Polynesians that we can have any hope of an approach to a solution.

To what problem or problems then can physical anthropology offer solutions? It can accurately define and describe the Polynesian groups. It can prove beyond reasonable doubt the racial origin and affinities of the Polynesians. It can designate fairly accurately to what branch of a given race they belong. It can determine the degrees of relationships between the various Polynesian groups. It can point out the probable types with which the Polynesians have come in contact and have intermixed during their migrations and in recent times. This data, when interpreted with the results of other phases of Polynesian research, may throw some light on the more general problems.

If physical anthropology is capable of solving the problems enumerated above, how has it succeeded thus far? The answer is, "Not at all." The racial affinities of the Polynesians are as confused and obscured in literature as are their origin and migrations. Saint-Hilaire (1861), Huxley (1870), Flower (1882), Topinard (1885), and Peschel (1874) describe them as mongoloid. Ellis (1829) and Lang (1877) assign them more specifically to the American Indian type. Pritchard (1866)

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groups them with the Malays. Deniker (1900) classes them as a special race of which he says "the relations are somewhat vague." Giuffrida-Ruggeri (1912) assigns them to a separate species including the Polynesians, the Indonesians and the Ainu. Quatrefages (1889) classes them as Caucasian. Giddings (1909) groups the Polynesians with the Europeans. Smith (1910) says they are generally acknowledged now to be a branch of the Caucasian race who originated in north Africa. Brown (1920) says: "Thus the hair and complexion, rather than the head-form, added to the tall stature and fine features, point back to the north-west of Europe." Keane (1908) describes them as follows: "Such are the Maori of New Zealand, the Tongans, Tahitians, Samoans, Marquesas and Ellis Islanders and Hawaiians, all of whom present a most remarkable uniformity in their physical appearance, mental qualities, customs, traditions, mythologies, folk lore and religious notions. That they are one people is obvious, and that they are an Oceanic branch of the Caucasian division is now admitted by all competent observers such as Dr. Guillemard who writes that the Polynesians are in no respect inferior to the average European either in complexion, physical beauty or nobility of expression." Lord George Campbell also declares that "there are no people in the world who strike one at first sight so much as these Friendly Islanders (Tongans). Their clear, light copper, brown colored skins, yellow and curly hair, good humored and handsome faces formed a novel and splendid picture of the genus homo; and as far as physique and appearance go they certainly gave one an impression of being a superior race to ours."

It is of interest to note that if we group the men quoted into two groups we get more uniformity of opinion. The biologists are almost unanimous in regarding the Polynesians as of mongoloid origin, while the ethnologists and others have a tendency to regard them as Caucasian.

If physical anthropology can answer these questions why all this confusion of ideas and opinions? The reason is obvious. It is simply necessary to remind you that physical anthropology is a biological subject. In the early days anthropology was chiefly physical anthropology. It is now far from that. Physical anthropology is only one of the many divisions of anthropology. But the transition has been so gradual and the traditions of the science so strong that even up to the present time

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it is customary for the various specialists in archaeology, linguistics, ethnology, anthropology and even history and sociology to carry on work in physical anthropology as a side line. It is taken for granted that no particular biological training or background is necessary to discuss its problems or prosecute its research. Even among ethnologists, our closest colleagues, it has come to be largely a course in surveying. One has only to know how to take a limited number of measurements of the body or skeleton to be an authority. To go a little further, I think it may be justly said the cephalic index has become synonymous with physical anthropology in the minds of a majority of ethnologists and scientists in closely allied subjects. This is shown clearly by the periodical revolts that are made by certain scientists when they call upon the cephalic index in time of trouble and find it wanting. One of the most recent secessioners is Brown (1920), who confesses as follows: "When I started out on my travels over and around the Pacific I had unquestioning faith in headform as the ultimate test of race. But as I proceeded there arose in my mind doubts and questions. . . . . . . I have now lost faith in the measurements of heads or skulls, at least in Polynesia." We can only say to Mr. Brown that his faith was too great. Even now it is shaken only by the chances of a head or a skull being artificially deformed. Yet disregarding the possibilities of deformation, few physical anthropologists would defend headform, at least as expressed by the cephalic or cranial index as the ultimate test of race. I have yet to meet the physical anthropologist who, given an individual or skull to identify racially, pays any attention to the cephalic or other indices.

In order to clear up certain misunderstandings that exist as to the scope and methods of physical anthropology, I would like to indicate briefly the principles underlying its technique and procedure.

We have two methods of attack. The first and most fundamental is the biological method. Here we rely upon anatomical characteristics for our racial relationships. Under this head come the form, color and texture of the hair, the amount and distribution of the hair on the face, limbs and body, the color of the eye, the color of the sclera, the form of the upper eyelid, the color of the skin, the form of the nose, lips and ears, the development of the glabella, the contour of the face and profile,

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peculiarities of the incisor and molar teeth, the development of the chin and hundreds of other similar observations. These are the characteristics upon which we depend in the main for determining racial relationships. They yield the best results only in the hands of a person who has given the subject serious thought and attention since they are expressed in terms of relative degrees, and one's description is restricted by his experience.

The second method is biometric and is not peculiar to physical anthropology. It is used in various other biological sciences. It is adapted to eliminate as far as possible the personal equation in description. It is based on the law of averages. Given any two sufficiently large samples of the same race, the average size of their shoes or collars should be the same. While these two characteristics are not used in practice, they illustrate the principle involved. Certain diameters which vary considerably in mankind and split rather definitely along the lines of racial or local groups, have been selected to add to and strengthen the descriptive data enumerated above. Among these are the diameters of the nose or nasal skeleton, the diameters of the fleshy ear, the diameters of the face, the maximum diameters of the brain case, and stature. The ratios of these diameters are called indices and certain of these indices notably the nasal, cephalic, craniofacial and facial have come to have a special biological significance. The nasal index comes the nearest to splitting along the racial lines, the cephalic the farthest. Yet one rarely hears of the nasal index, while the cephalic index figures prominently in every anthropological or semi-anthropological paper or discussion. The nasal index has its shortcomings and does not distinguish between types of noses having similar proportions. All of these indices are rough expressions of something that exists in nature. They are better than verbal descriptions but must be interpreted by one who has seen the material involved at first hand. Attempts to classify mankind by consistent adherance to the cephalic, nasal or other indices have yielded weird results, as they must, for mankind in its differentiation into groups has not been conveniently consistent. Only when both of these methods of attack are used in the proper proportions to meet the demands of the case in hand can we hope for good results. The application of a universal formula of attack results in a waste of time, money and energy, and the results are most often obscured by details. Each area

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of the world presents its own peculiar problems which must be attacked by methods adapted to its peculiarities.

Another important consideration is that the investigator should be capable of distinguishing impressions from facts, that he be capable of determining what is typical and what is atypical or extreme. Extremes strike the untrained observer more forcibly than the mean or average. A good example of this may be seen in the section quoted above where Keane quotes Lord George Campbell's description of the Tongans as having yellow hair. Surely this is not the average form and color of hair for any Polynesian or Melanesian group. Another interesting episode is Brown's attempt to explain the "negroid" characteristics of the Polynesian nose. He says, "But there is another feature that is manipulated in babyhood; the nose; the nostrils are carefully flattened out as in negroid faces . . . ; we may, in fact, conclude that his negroid form was not the nose that nature endowed most of them with." Mr. Brown does not seem to appreciate the difficulties involved in deforming the nose permanently. It could not be accomplished in babyhood, since the nose is one of the last things to reach its adult form and size. That the Polynesian nose could be produced with such uniformity by such methods is beyond belief. There are hundreds of such ways in which one who has not made physical problems his primary interest may, and usually does, go astray.

The old method of sending a man who is a specialist in one field out with a basket to collect data in all fields, has not, and will not yield the most desirable results. If you wish an example look to America. Over 180 tribes or groups of American Indians have been studied and described from the standpoint of physical characteristics by men more or less interested and more or less trained in the subject. In many cases the data has been the by-product of an expedition for other purposes. The observer has had no particular problem in mind, but collected the data simply becaues it was considered a good thing to do. As a result what do we know of the interrelationships of the American Indian? Very little. There is probably not more than one or at most two men who have any idea of their relationships, whether there is one type, or two, or a dozen. And whatever ideas this man or these men may have are based not on the data collected by others, but on their own research.

The only way to obtain satisfactory results is to have a problem, map out the procedure and attack it logically and con-

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sistently. The physical problem in Polynesia is a separate problem, at least insofar as its prosecution is concerned. Its satisfactory solution can be accomplished only by sending out trained men to a fair sample of the islands to devote their entire time to this problem. You would not send out an archaeologist, a linguist or an ethnologist to study the interrelationships of the fauna or flora of an area. Why send them out to study one of the most complicated of any of the animals groups—man?

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THE ANTHROPOLOGY OF THE HAWAIIAN RACE

By Alfred Tozzer

From an anthropological point of view there are three angles of approach to the study of the Hawaiians. The first of these is a comparative study of the Hawaiians in relation to other Polynesian people—the origin of the Polynesians—in other words that most popular, most difficult, and most nebulous of subjects. The second means of approach is a physical study of the Hawaiians as a racial unit. This investigation is now being carried out by the Bishop Museum under the immediate direction of Mr. Louis R. Sullivan. The third angle is an investigation of the Hawaiians in their relations to other peoples, the racial mixtures now present in the Territory. This is the subject which I wish to discuss very briefly at this time.

Let us consider, first of all, the history of foreign immigration to these islands, and influx of peoples which has brought about one of the most complex problems of miscegenation now available for study.

TRADITION OF WRECK

Tradition states that about 1528 at Keai in South Kona, Hawaii, a foreign vessel was wrecked. The captain and his sister alone were saved. Practically all authorities agree that this vessel must have been Spanish. It is known that Cortes at about this time fitted out several exploring expeditions from the Pacific coast of Mexico. The first of these, in 1527, consisted of three vessels, two of which never returned. It has been assumed by many that the vessel wrecked on the Kona coast was one of these ships. Tradition goes on to tell us that this captain and his sister were kindly received by the natives. They intermarried with the Hawaiians and it is said that they became the ancestors of certain well known families of chiefs. It is generally believed that the present reddish haired Hawaiian called "Ehu" is the result of this Spanish influence. I think this supposition is decidedly doubtful.

Returning to the historical aspects of the question, there is little doubt that these islands were discovered in 1555 by the Spanish navigator, Juan Gaetano. The islands seem to have

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been incorrectly placed on early Spanish charts from about this time.

It was not, however, until almost 225 years later, in 1778, that the voyages of Captain Cook made the islands generally known. From Cook's time onward, there was a constant succession of voyages to the Islands among these being Portlock and Dixon, Young, and Vancouver. The latter in 1791 found 14 Chinese merchants already located there.

The arrival of the first American missionaries, just 100 years ago, marks the first distinct immigration of a foreign people. The wholesale arrival of alien peoples did not begin, however, until the latter part of the 19th century. The influx of foreigners was almost solely due to the necessity of obtaining cheap agricultural labor for the sugar plantations, which were rapidly being developed.

EARLY COLONIZATION

Before enumerating some of the successful attempts at colonization let me review some of the less successful efforts to bring other peoples into these islands. Kamehameha III wished to have the few inhabitants of Pitcairn Island brought to Hawaii. In 1868 an attempt was made to introduce Polynesian peoples. Ten years later 2000 inhabitants from the Gilbert Islands were actually brought here. Nearly all of these were later returned to their homes. An East Indian immigration was planned in 1867 but it was never carried out. In 1870 a white colony was placed on Lanai. This met with disaster. Seven years later a Hindu immigration was contemplated.

Of the peoples other than white who have played a great part as a racial ingredient in Hawaii, first place goes to the Chinese. The first colony, consisting of 180 coolies, arrived as early as 1851. With the establishment of the Bureau of Immigration in 1864, a definite policy of oriental immigration became effective and in the following year 500 Chinese arrived. In 1866 the Chinese in the Island numbered 1200; in 1878, 6000; and in 1886, 21,000. This number has remained practically constant ever since.

Far less important as a racial factor from the point of view of miscegenation are the Japanese. The first came in 1869, a colony of 48. In 1890, there were over 12,000 and in 1910 almost 80,000.

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THE PORTUGUESE ELEMENT

The Portuguese were practically unknown here until the last quarter of the last century. There were, of course, sailors who came here in early times on the whalers, mostly from the Cape Verde Islands. They furnish a negro strain in some of the present day natives. The first large body of Portuguese, 180 of them, came in 1878 from Funchal. In the seven following years almost 10,000 arrived, mostly from the Azores and from Maderia. The Portuguese represent the largest element in the European population of the Islands at the present time.

The Koreans and Filipinos were the last of the oriental peoples to arrive. The Koreans began to arrive in 1900 along with the Porto Ricans. The Filipinos were brought in 1909 for the first time.

Let us now consider the main components of the present population. The last figures published are from the census of 1910. The estimates of the population in 1919, published in Thrum's Annual for 1920 differ considerably in the proportions of the different elements of the population from the enumeration of ten years ago. Taking the 1910 figures the Japanese stand at the head, forming 41 per cent of the total population. This should be borne in mind when we come to consider the small part of the Japanese play in racial mixture. The percentages of the other nationalities are as follows:

	1910	1919 (estimate)
Hawaiian,	13.5	8.5
Portuguese,	11.5	9.4
Chinese,	11.2	8.6
White [1]	7.7	11.7
Hawaiian-White,	4.5	6.2
Porto Rican,	2.5	2.
Korean	2.3	1.9
Hawaiian-Asiatic,	1.9	
Spanish	1.	
Black	.3	
Filipino,		8.3
All others,	1.4	.2

[1] American and European other than Portuguese and Spanish.

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RECENT DATA

I next propose to present a sample of mixtures found in 200 individuals whom I have measured within the last three weeks. I regret I have not the figures for 300 other persons measured by me in 1916. It is not claimed that this sampling is a fair test of the relative frequency of pure and mixed bloods but it will indicate the variety of crossing available for study here in the islands. These measurements were made for the most part at a pineapple cannery, on the docks, and at the Summer Normal School. 34 per cent of those measured called themselves pure Hawaiians.

The Hawaiian-White mixture formed 35 per cent of the individuals investigated, running all the way from ½ Hawaiian and ½ White, to ⅞ Hawaiian and ⅛ White, and ⅛ Hawaiian and ⅞ White. There is little doubt that the census figures giving the Hawaiian-White mixture as 4.5 per cent of the population is far too low an estimate. An improvement in collecting these data could be made.

The frequency of this mixture is probably due far more to racial and social causes than in the case of the Hawaiian-Chinese mixture, where it was due to the relatively few Chinese women in the country.

JAPANESE DID NOT MIX

The Japanese who were in a similar position regarding the small available choice of their fellow country-women as mates did not intermarry with Hawaiians to any appreciable extent. The advent of the "picture bride" is too recent to have played a part in this almost total lack of Japanese-Hawaiian mixture. I found only 2 per cent of those measured of Japanese-Hawaiian descent and this in spite of the fact that the Japanese furnish over 40 per cent of the population.

Of the 200 people studied, 5 per cent were Hawaiian-Chinese-White in varying mixtures, the greater number being ½ White with ¼ Chinese and ¼ Hawaiian. Four per cent had negro blood. This negro element came, for the most part, from the Cape Verde islanders. Finally 2 per cent of those measured came into a miscellaneous class which includes traces of Malay, Tahitian, Samoan, East Indian, different tribes of American Indian and a Mexican.

Let me give only 2 cases in detail. The first mixture was ⅜ Hawaiian, ¼ Chinese, ¼ White, ⅛ Negro. The second

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was ¼ Hawaiian, ¼ Porto Rican, ¼ Spanish, ⅛ Portuguese, ⅛ Northern European.

Nothing can be said at this time regarding the racial characters of these mixtures, the special racial traits inherited in varying degrees as shown by the head, face and body measurements. This is a subject for a more extended treatment than can be given at this time.

FIELD FOR STUDY

I have said enough, however, to indicate that this paradise at the crossroads of the Pacific has been in very truth a centre of miscegenation perhaps not equalled in the same number of people anywhere else in the world. This study of the racial complexity here opens up a fertile field for the eugenist, the student of heredity, the sociologist, the psychologist, and the economist as well as for the anthropologist. I cannot urge too strongly upon the local scientists this unexampled opportunity for profitable research which they have in their midst. This situation shows in very truth that the hands across the Pacific are in many cases the hands of marriage.

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NOTES ON POLYNESIAN FEATHER WORK

By John F. G. Stokes

No doubt the wearing of feathers originated in the motive of displaying trophies of the chase or hunt, in a manner analogous to the custom of wearing human hair and other substances as trophies of battle. As trophies or "first fruits" of the hunt, they were also offerings to the gods. The Polynesian veneration for feathers may have resulted from the latter association, or, may have been remnant of a great bird-cult.

In using the terms "religion" and "sacred" in this context the Polynesians' concepts must be understood. These people as exemplified in Hawaii attributed a divine origin to their kings and venerated them as gods. This did not imply that humans were raised to the heights conveyed by our ideas of divinity, but that gods, to Polynesians, were little more than human.

Gods were present in many shapes. In human form they differed from people only in substance and in unlimited supernatural power. They intermarried among themselves and with humans, and begat children. The distinction between kings and gods was the matter of mortality, but the transition from immortal gods to mortal kings in the line of divine descent, has not been satisfactorily explained.

We do know, however, that the Polynesians believed in the ability of humans to implant supernatural power in inanimate objects, and thereby create a god which would do the bidding of its human creator. It was much practiced in the black art, and had its parallel in the investiture of Polynesian kings, a ceremony by which the divine power was infused into the king's person, and which I will presently describe.

In Polynesia the use of feathers was confined, in general to the chiefly or kingly caste, and to worship.

The sacred color was primarily red, as was the sacred feather. The Polynesian red-feather cult had reached the height of its development in the Society Islands at the time they were first explored by foreigners. Red feathers had then become the necessary medium for invoking the great gods, particularly the god of war. All prayers in and out of the temple were said over a small bunch of red feathers held in the fingers. The god himself could be implanted in red feathers by contact and

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prayer, and his presence might thus be simultaneously transferred to hundreds of homes, while his image remained in its place in the temple. The war god was worshippd in bird form in Samoa and in bird form or effigy in the Society group, and similar conditions might have been noted in other islands. Effigies of birds were found about the tombs of the Society and Marquesas islands, but this may have been the effect of a form of bird-totemism which was prevalent in Polynesia. A tern cult was observed in Easter Island and, as is reasonably shown by Balfour, seems to have been evolved from a frigate-bird cult analogous to that in Melanesia.

Rarity of feathers played a minor part, as the Hawaiian feathered representation of the war god remained principally red, even though red feathers were so common on Hawaii as to have been entirely replaced in the royal cloak by yellow. At the same time other colors were to be found creeping in as complementary to the red.

The girdles were emblems of royal investiture, equivalent to the crowns of monarchy, but as fetishes were far more potent because they imbued the wearer with power direct from the god. By inference, their use was limited to certain pure lines of purported divine ancestry.

Records of four girdles have been preserved, one each from Raiatea[1] and Tahiti[2] or the Society group, and two from Hawaii. The Hawaiian specimens I will call a sash and cordon, respectively, after the manner of wearing. The sash[3] is nearly in fragments, but the cordon[4] is almost perfect. The condition of the specimens, and a difference in the technique, indicate that the sash was the older and it was probably the predecessor of the cordon.

All the girdles were of feathers on a groundwork of netting. The predominating color is red, but in three of them yellow was also present, and shadings of black in two. The Tahitian and Raiatean sashes were incomplete, as they were in continuous process of manufacture. In Raiatea, a piece was added on the accession of each new king. The Hawaiian speci-

[1] Tyerman & Bennet, Journal, vol. 1, p. 527, London, 1831.
[2] Cook's Third Voyage, vol. 2, p. 37; London 1784; and Ellis, Polynesian Researches, vol. 3, p. 180, London 1853.
[3] Mem. B. P. Bishop Museum, vol. II, p. 154, 1906.
[4] Mem. B. P. Bishop Museum, vol. VII, p. 34, 1918.

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mens differed from the others in that they were complete; also they were finished with human molars. The proportional measurements of the four specimens varied.

The Hawaiian emblems have only come to light within the last few decades, and we have no information concerning the ceremony of investiture. The late King Kalakaua claimed that the cordon was one with which King Liloa invested his son Umi in the temple of Paakalana on the Island of Hawaii. This period was about 1500 A. D. In Tahiti and Raiatea the investiture was always conducted with one or more human sacrifices, and at each ceremony an addition of feathers was made to the sash. As an illustration of the alleged dynamic force transmitted through these specimens, I might mention that there was a needle attached to the Raiatean sash, with the tradition that no stitch was taken but thunder was heard in the heaven.

Peculiar sacredness is attributed to the island of Raiatea. Ellis states that it was the cradle of Polynesian mythology and the birthplace of the great Southern war god, Oro.

During a ceremony at Tahiti in preparation for war, the sash and the representation of the god Oro were wrapped up in similarly shaped bundles and laid side by side on the altar. There was as much veneration paid to the sash as to the idol, which latter was merely an uncarved log of wood with red feathers attached. On the accession of a new king, the heir was invested with the sash by the high priest. As the priest girded on the emblem, he prayed that the king's influence might be extended far over the sea. He then described the sacred nature of the girdle, concluding with the words, "This, O King, is your parent," meaning, as Ellis stated, that all the king's power was derived from the gods.

We have been able to trace this system of investiture back to the year 1250 A. D., when, as Percy Smith shows, Tangiia, a Tahitian chief, defeated in a battle in which his sons were killed, was in flight for Rarotonga. He was engaged in investing with the sash the son of a chiefly relative when the dreaded enemy came suddenly upon him, and the ceremonies were suspended. Tangiia finally settled in Rarotonga and had other sons, and undoubtedly the sacred emblem went with him. On account of this tradition I believe that the rite was continued in Rarotonga, but as the Hawaiians have been so secretive about

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their emblem of royalty it is probable the Rarotongan emblem has not come to light for a similar reason.

An earlier date for the custom was set by a Hawaiian tradition (borrowed from the South) as it is stated in a chant that Hema went to "Kahiki" (a portion of Polynesia not identified) to get the red-feather girdle, but he died instead. The period of Hema is set as the seventh century by Percy Smith, who places the date of the arrival of the Polynesians in the Pacific as only a few centuries earlier.

Tahitian myth carries the custom back to the beginning of time when gods begat kings by the common people, kings who on account of the plebeian adulteration were not entitled to wear the sacred emblem.

New Zealand was too large a country and its tribal interests too varied to be united under a single Polynesian monarch. Its chiefs also were probably too distant from the line of divine descent. This may account for the investure of an idol, instead of a human with a red-feathered fringe.

We get a continuity of form in the sash which is merely incidental and controlled by the manner in which the emblem must be worn. The material on the other hand is controlled by the religious purpose of the garment.

I have shown that the making of feather girdles was a very sacred undertaking. In Hawaii the manufacture of royal cloaks and helmets was also conducted under the tabu, but as far as known, was not accompanied by human sacrifice. The helmet was probably of greater regard than the cloaks as it was to come in contact with the head—the most sacred part of the body. The restrictions during manufacture of feather garments were probably general in Polynesia, as implied by the description of the mourner's robe in Tahiti.

I have been able to find no reference to the existence of the girdle in the other large Polynesian groups. The perpetuation of the custom would require a hereditary monarchial government of an island or group by very tabu kings. The topography of the Marquesan group would aid the independence of valley chiefs, tending towards tribal conditions as in New Zealand. In Tonga the necessary conditions seemed to have existed. In Samoa the idea of monarchy was recent. [5]

[5] Since reading this paper I have been informed by Dr. W. E. Safford that he was well acquainted with the Malietoa family and that he was sure that no custom of investiture with a feather girdle was in vogue in Samoa.

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With the evidence at present available, we may tentatively conclude that the right of investiture with the girdle belonged to a Polynesian family of high tabu, centered in the Pacific in the Society Islands. The degree of sanctity attributed to the feather girdles, however, was probably far greater than that assigned to any other form of feather garment.

I now wish to emphasize points of difference between the northern and southern Polynesian helmets or headdresses. The former is represented by one general type, the Hawaiian helmet. The southern headdress was in general of frontlet form and retained this feature even in its greatest development—the Tahitian *fau* mentioned below.

The theoretical evolution of the southern headdress can without difficulty be traced from detached feathers used for head ornamentation as in New Zealand, but we need only follow it after it took on a frontlet form. It seems to have passed through one of two such forms, either a string of feathers bunched together as found in Tonga,[6] or in a bandage of coir holding erect plumes of feathers as in the Marquesan group.[7] Most likely it was from both. The combination may be illustrated by another specimen[8] from the Marquesas, where we have a feathered frontlet, widely extended, with strings on the inside for plumes.

To return to Tonga, one of the frontlets has just been mentioned but there was another,[9] very elaborate, worn only by the king. It was of the coronet type, a cap with long erect feathers around its border, reaching across the forehead and extending backwards. Small red feathers, in the manner of thatching, were fastened to each erect feather for its full length, and the result was a conspicuous headdress.

The caps of the Cook islanders, were broad bands with numerous feathers and high plumes. One form of those in the Austral Islands was described as well made and graceful, in comparison with the Tahitian specimen.. It was of cane-work and stiff cloth. The lower part of the front was of red and green feathers, and above was a line of tropic bird feathers fixed to a frame. The description conveyed the idea of a

[6] Cook's Second Voyage, Pl. XXI, fig. 1.
[7] Cook's Second Voyage, Pl. XVII, fig. 4.
[8] Mem. B. P. Bishop Museum, vol. 1, p. 448, fig. 77, 1899.
[9] Cook's Third Voyage, Pl. XVIII.

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frontlet combined with a plumed fringe as illustrated by the *fau* mentioned below, but of more modest proportions.

The *fau*[10] of the Society islands, a war dress as were the others, was worn by only the most distinguished men. The wearers served as rallying points in battle. This high frontlet was of green feathers, bordered, in white, and fringed with the long tail-feathers of the tropic bird. Its support was a cylinder of open cane work, carried to a height, as described, of two or three feet. In Tahiti there was also a frontlet of cloth, with a bunch of tropic-bird feathers pointing forward from each end.

The only other examples from the South are from Easter Island, where there was a frontlet of numerous erect chicken plumes.[11] There was also a circlet of feathers for the head. The Samoan war headdress was principally of hair but with a few tropic-bird feathers placed erect. It did not convey the idea of a feather frontlet.

In the North, I can find but one resemblance to the frontlet, i.e. in the feather wreath called *lei* worn by women, and somewhat analogous to the Easter Island circlet. The Hawaiian feather helmets were in another class, of strong yet light wickerwork, close-fitted to the head, even to provisions for the ears. They were stout enough to withstand the blow of a club. The range of forms may be shown by two specimens, one comparatively simple in design[12] and the other with open supports for the crest.[13] The main feature is the crest, which has been taken by some as evidence of early Spanish contact. The Hawaiians were good imitators, as were Polynesians generally, and made feather hats exactly after foreign pattern. If a model of a Spanish helmet of the period were placed by the side of a Hawaiian helmet it would be seen clearly that one was not imitated from the other. Brigham, when discussing the origin in his account of the Hawaiian feather work[14] pointed with more reasons, in the direction of Melanesia, where the crest is found. He finally suggested a local Hawaiian development.

[10] Parkinson's Journal, Pl. XI, London, 1773. This plate should be examined together with Hodge's illustrations in Cook's Second Voyage, Pl. LXI.

[11] Cook's Second Voyage, Pl. XLVI.

[12] Mem. B. P. Bishop Museum, vol. I, p. 5, fig. 2, 1899.

[13] Mem. B. P. Bishop Museum, vol. I, p. 447, fig. 10, 1899.

[14] Mem. B. P. Bishop Museum, vol. I, p. 40, 1899.

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The Hawaiians lost touch with their southern neighbors about the year 1300 A. D. so that they were left for 500 years to develop by themselves before Cook's arrival.

Some interesting features are suggested by the comparison of the girdles and headdresses. It is evident that contact of the Hawaiians with Southern Polynesia is shown by the girdle investiture, the custom having probably been borrowed from the Society Islands. The very sacred nature of the girdle would be sufficient to insure the continuity of the custom until modern historical times.

On the other hand the Hawaiian head-dresses, and other feather work in some degree, would imply a separation of long duration from the Southern groups. There was enough intercommunication among the Southern Polynesians to explain the continuity of the frontlet form of headdress, and there is little doubt that if the Hawaiian helmet had been evolved before communication ceased with the southern groups, its form would have been found in the latter islands. The last traditional departure from this group for the south was that of Laamaikahiki, about 1300 A. D. While I am inclined to believe that the Hawaiian helmet was locally developed since that date, it should be pointed out that there are traditions of the arrival here of more than one company of strangers between that time and the coming of Captain Cook. The sacred nature of the headdress was evidently of lesser degree than that of the girdles, or there would have been less variation.

The references to the girdles may also serve to place one of the localities known to the Hawaiians as "Kahiki" (Hawaiian form of Tahiti.) The Hawaiians claimed that they came from "Kahiki" but applied the name in general to any foreign country.

The Hawaiians have several groups of traditions, one to the effect that the first Hawaiian was Wakea (390 A. D., Smith's chronology) who introduced taro into the Hawaiian Islands. Another claim is that Hawaii-Loa (200 years earlier) discovered and settled these islands. There are no accounts of other immigrants until the twelfth century A. D.

Fornander[15] localizes these early Hawaiians elsewhere, and while suggesting in various parts of his work the probability of a very early settlement in Hawaii, makes with necessary reser-

[15]Polynesian Race, vol. 1, p. 168.

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vations the following propositions deduced from a study of the old traditions:

1. At the close of the first and during the second century A. D., Polynesians first arrived in the Pacific, establishing themselves in Fiji and spreading to Samoa, Tonga, and other groups eastward and northward. (Percy Smith's chronology, 390-450 A. D.)

2. During the fifth century Polynesians settled in the Hawaiian islands. (Smith, 650 A. D.)

3. During the eleventh century and for five or six generations afterwards parties from the Marquesas, Society, and Samoan groups arrived at and maintained an intercourse with the Hawaiian group. (Smith, 1100-1325 A.D.)

Percy Smith mentions the probability of two groups of Polynesian arrivals in the Pacific, whose periods might be divided by the year 450 A.D. "From the want of any direct traditions amongst the Samoans and Tongans, it is probable that they had preceded the others and were the first to enter the Pacific. They have been so long in their present homes that all traditions of their arrival is lost, and hence they have come to look on themselves as autochthones."[16]

Commencing approximately with the year 450 A.D. and continuing for some centuries afterwards, there followed other Polynesians who brought new customs, settled in Fiji, Tonga, the Samoan coastal region and extended through the Pacific. These people, called Maori-Rarotongans by Smith, were in time able to control all the earlier Polynesians, except the Samoans. According to Smith's chronological table, they reached the Marquesan group in 675 A. D.; Tahiti, prior to 850 A. D.; New Zealand 850 A. D.; Rarotonga 875 A. D.; Paumotu group 1000 A. D., and, as he infers, Hawaii in 650 A. D. The last was probably not until 1100 A. D.

The early Tongans were apparently overwhelmed by the later migrants, so that the lines of demarkation between the earlier and later cultures are not now distinct. The Samoan culture in the main survived, with such additions as contact would bring, as the Samoans were able to repel the later people.

If we compare the Samoan culture with that of the Society group, where the later migrants appeared to have had the greatest influence, we find in Samoa, among other features,

[16] Percy Smith, Hawaiki, p. 153, 1910.

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platformed foundations for temples, and an absence of hereditary king-ship, of idols or images in worship and of human sacrifices. In the Society group, the last three features were characteristic, and the temples were walled enclosures except for such as may be traced to earlier influences.

The features mentioned above as Samoan were in existence in the Hawaiian islands prior to the twelfth century when the later migrants began to arrive in this group.[17] We may therefore consider the earlier people as of the same stock as those of Samoa though not necessarily coming from that group. I do not believe that the arrivals in Hawaii of 650 A.D., of which there are no Hawaiian traditions, were of the later migrants, and consider it more probable that they were of the earlier stock from the south who had previously spread through the Pacific and were being displaced through the pressure of the later migrants.

It is not difficult to choose the period to which the royal girdle investiture belonged, as the hereditary king-ship and the evident growth of priestly power, as shown by the change in worship, would mark it as the second period.

It was therefore an acquirement after the early migrants, now represented by the Samoans, had left the parent stock. But whether it resulted from contact with other people or from development of the idea of royalty it is difficult to surmise. It is equally difficult to surmise if its development took place in the Pacific. I will content myself therefore with the attempt to show that it became localized in the island of Raiatea and thence spread to some of the other groups.

It is more convenient to begin with Hawaiian traditions. In reading Fornander's account of the arrivals in Hawaii during the later period, we find among others the names of:—Nanamaoa, whose son Nanakaoko, a chief of considerable note on the island of Oahu, established the sacred chiefly birthplace called Kukaniloko; Paumakua, whose son Haho established the Ahaalii on Maui; Moikeha, the chief of southern extraction born on Hawaii who went to "Kahiki" and returned to the Hawaiian group, becoming king of Kauai through his marriage with the daughter of the Kauai king; and Pili-kaaiea, who became king of Hawaii (about 1200 A.D., Smith's chronology).

[17] Fornander, Polynesian Race, vol. 2, pp. 58-67, and Kepelino Ms. (Catholic Mission, Honolulu.)

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As the girdle investiture has been attributed only to the island of Hawaii, the choice would naturally incline to the last mentioned. There are however other circumstances seeming to confirm this.

One of the arrivals of the later period was a priest named Paao, whose first reported action after landing on the island of Hawaii, was the building of two temples of the enclosure type. Finding that conditions were favorable for the establishment of a new king, Paao sent to "Kahiki" and induced Pili-kaaiea to accept the throne of Hawaii. The latter was installed in his new office without recorded opposition at the time from the island chiefs, a condition which can only be explained by the probability that an unusually high tabu family rank was claimed for him and that the claim was admitted by the resident chiefs.

As far as traditional evidence is of value, the circumstances as above mentioned, after considering the claim for distinction of the other arrivals, point to Pili-kaaiea as the king who introduced the girdle investiture into Hawaii.

It is sometimes dangerous to place reliance on coincidences in names, but I should point out that Fornander was in some doubt in regard to the spelling of Pili's name.[18] *Ka aica* means "the fatigued," but *kaai* is Hawaiian for "girdle" and *ea*, "spirit, vital breath," so that the combination might with some slight stretch of the imagination be translated as "divine girdle." On the other hand, if the name were spelled Pili-kaaiia, it would mean "girdled Pili," and leave no doubt as to the significance of the name. Fornander's doubt as to the correct spelling of the name leaves the way open for this suggestion.

Fornander[19] was of the opinion that Paao and Pili-kaaiea came to Hawaii from Samoa on account of the traditions that Paao came from Upolu and owned lands in Vavau, (Tonga).

Percy Smith[20] in his researches has ascertained that Upolu was also one of the ancient names of Tahaa, the island of

[18] In the first volume of the "Polynesian Race" it occurred three times, twice Pili-kaiaea and once as Pilikaeaea. In the second volume, it was mentioned six times, with similar letters; three times as "Pili, surnamed Kaaiea," twice as Pilikaaiea, and once as Pili Kaaiea. There are four forms of this term, *kaai*, *kaei*, *kahai*, and *kahei*, the distinctions between which the best-informed Hawaiians of today cannot explain. Malo, the Hawaiian historian uses *kaai*. It was probably a term not in common use.

[19] Polynesian Race, vol. 2, pp. 33-35.

[20] Percy Smith, Hawaiki, p. 262, 1910.

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Raiatea, and that Vavau was a former name for Polapola, about 20 miles to the northwest.

Ellis[21] has referred to the former importance of Raiatea and its sacred place of Opoa, from which "distant colonies are said to have proceeded," to which disembodied spirits returned, and offerings were brought not only from the Society group but "from the more distant islands to the south and southeast." It had an enclosed temple where "human immolation was frequent." Tyerman and Bennet[22] mentioned that Tamatoa, king of Raiatea, "was of the genuine royal blood which from time immemorial had supplied princes to all these [Society] islands, both windward and leeward." Percy Smith[23] shows that a colony has even proceeded from Raiatea to New Zealand.

These combinations of circumstances seem to point to Raiatea as the island from which Pili-Kaaiea came to Hawaii and that the "Kahiki" of the Hawaiians concerning this king referred to Raiatea, not Samoa as believed by Fornander.

It is probable that the Tahitian girdle-investiture previously described was adopted from Raiatea, but this matter cannot be cleared up without reference to Tahitian and Raiatean traditions which are not available here.

A previous reference to the time when kings[24] born in Tahiti who were not entitled by blood to wear the girdle may have referred to the early Polynesian period, or to a time before one of the Raiatean family was called to the throne of Tahiti.

[21] Polynesian Researches, vol. 2, p. 315, London, 1853.
[22] Journal, vol. 1, p. 519, London, 1831.
[23] Percy Smith, Hawaiki, p. 263.
[24] Chiefs(?) as the Polynesian terms are not always definite.

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HAWAIIAN TEMPLE STRUCTURES

By Thomas G. Thrum

Among the various archaeological remains found in Hawaii probably the heiaus (temples) take first place as material for consideration, not only for their antiquity but for the prominence they held in all the islands of the group for both priestly and political power. No other reason can be assigned for the number of temple ruins yet remaining, and the vaster number revealed to us by history and tradition. This field of inquiry and investigation has been entered upon only within the past few years—and that not exhaustively—yet the pioneer effort has been rewarded by the locating of some four hundred and thirty heiaus and heiau sites on the islands of Hawaii, Maui, Molokai, Oahu and Kauai.

Tradition marks two well defined periods in the temple structure and worship of these islands determined by the advent of Paao, the high priest from the Southern Pacific, in the eleventh century.

The type of structure prevalent prior to his arrival differed outwardly by having a pyramidal truncated form, a few ruins of which were in evidence at the opening of this century, two on Hawaii, and one each on Maui and Molokai. Whether this was a universal type or a special form is not known. It is not unlikely the latter, for those that survived to share in the overthrow of idolatry by Liholiho in 1819 were above the average in size. It is quite possible that these may have been structures of the later period built after the ancient plan, as memories of the past, for it is beyond probability that structures of loose stones, without mortar or adhesive material, characteristic of all Hawaiian stone work, would survive several hundred years.

Tradition locates the erection of the first temple in these islands at Waolani, Nuuanu valley, to identify it with Wakea, ancestor of the Hawaiian race. The general plan of this original heiau is set forth by native historians, and is said to have been followed down to the time of Moi, a noted priest of Molokai, whose temple of Maniniaiake, at Pelekunu, conformed thereto. Under this early regime, the heiau with its presiding chief, officiating priest, and prepared sacrifices, were in plain open view of the assembled congregation, who heard the prayers and saw

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the sacrifices and could respond intelligently to the invocations of the priests.

Heiaus were of several kinds—all open to the heavens, never under cover—and it is somewhat remarkable that no two are found alike in all the islands, notwithstanding the original plan laid down. They not only differ in plan and size for the kind of service intended, but are affected by location, some being constructed upon carefully leveled ground, and pebble-paved, others conforming to the natural contour of a possibly advantageous hill site. This may not apply to the earlier period of open type structures.

Paao, already referred to, on his arrival landed at Puna, Hawaii, and there erected his first heiau known as Wahaula, a walled and paved structure of the *luakini* class, 72 feet by 132 feet, remains of which are still in fair order, owing to repairs at the hands of various kings down to the time of Kalaniopuu, its last renovator, about 1775. A high stone enclosure reaching nearly to the shore line gives it an extensive adjacent working area, most of which was at one time paved and pebbled. Its model, made to scale, showing a quadrangular or parallelogram form characteristic of the new regime, may be seen at the Bishop Museum. Paao's next structure was that of Mookini, at Puuepa, Kohala. It had massive walls, 135 feet by 267 feet still in fair condition. Both of these temples are of the human sacrifice class, and marked a new epoch, for with the introduction of this weightier of penalties to the temple services came also the introduction of several new gods, when worship of the visible image took the place of that which had hitherto typified the unseen deity. The new type of structure among other things, included the *lua pa'u* (bone pit), and the *hole-hole stone* whereon the flesh was separated from the bones of a victim. The bone pit of Mookini is within its seaward wall; this feature at Wahaulu is served by the nearby cove of the sea-coast, while the hole-hole stone is outside the walls of the former and within that of the latter. The massiveness of Mookini's walls is unusual, the height having been over twenty feet, with a width or thickness of eight feet on top and thirty feet at the base. Fornander says: "The stones of which it is built are said to have come from Pololu valley, some ten miles distant, which, according to tradition were passed by hand from man to man the entire distance, a feat requiring at least 15,000 men."

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All the principal islands of the group show a number of extraordinarily large heiaus, indicative of priestly power, royal ambition, and a dense population. Among the more notable of these temples is that of Malae, in central Wailua, Kauai, a walled and paved structure 273 feet by 324 feet in size, of traditional Menehune construction, its corners buttressed with thirteen foot walls. Only two of this type have so far been discovered.

Oahu's most notable heiau is that of Puu o Mahuka, situated on the slope of Pupukea, overlooking Waimea. It is a walled temple, once paved, of double end-to-end structure, running 467 feet in length, the upper section being 127 feet in width by 281 feet in length, and the lower division 168 feet in width by 186 feet in length. Its internal features also differ in several respects from any other found.

Maui has the distinction of possessing two ruins of unusual interest; that of Loaloa in the Kaupo district, and of Kanekauila in the adjoining Kipahulu district. The latter occupies a clear space of 250 feet by 173 feet, on a knoll whose seaward face was built up and leveled with a considerable amount of stone work. The lower walls and much paving still survive, although the ancient temple features have been removed by time. Its site has been utilized the past fifty years or more by the Catholic church of the district.

But for size, amount of stone structure, and type (if it could be understood in its working order) the palm must be accorded to Loaloa, a walled, paved temple of two or more sections built up high at the point of a hill spur in the land of Kumunui, Kaupo, by three or four tiers of stone, the seaward face of which measured 101 feet. The full length of Loaloa could not be ascertained, its inner section being lost in the jungle; but measurement of the outer division gave a length of 264 feet for apparently the smaller half. Running nearly across the heiau some twenty feet from the higher and less disturbed section is a distinct path of broad, smooth stones, as in the temple of Puukohola, at Kawaihae, Hawaii. This structure is credited to King Kekaulike, about the year 1730.

Molokai's right to heiau distinction is in her temple of Iliiliopoi (referred to by Fornander as Iliiliopae) in the Mapulehu valley. It is built across the end of a ridge by retaining walls of several terraces, and is noted for its size, its age and

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traditions. It is much reduced from its original dimensions, a large section having been carried away by a heavy flood. It is said originally to have covered three times the present area and was of a different type, possibly a walled temple. Its reconstruction is credited to Kaalauohua, a ruling Molokai chief of the sixteenth century. Its ruins show a floor surface 85 feet by 268 feet, and a cruciform pavement similar to some temples on Hawaii ascribed to Umi.

Besides those of Paao on Hawaii, already dealt with, are several in the district of Kona worthy of note, for no less than thirty-seven heiaus have been identified in this historic district of kingly and priestly power, several of which are attributed to Umi, and are known by the peculiarity of his stone work. One such temple was erected on the top of Kukii hill, in the Puna district, the stones of which were so closely fitted that, according to native tradition, a spear of grass could not be inserted between.

The crowning structure of this ancient king is the Ahua a Umi, situated on the high plateau of Kona between the mountains of Hawaii on the slope of Hualalai, at some 5000 feet elevation. The ruins of today show much change from the plan given by Wilkes in the account of his visit in 1841, which may be readily accounted for. This structure, erected about the year 1520, is a walled memorial of several divisions, with eight stone piles surrounding it. What is termed the heiau, though tradition says Umi planned it as his monument, now measures about 74 feet by 93 feet, with walls seven or more feet high. The stone piles around the structure, some ten to twenty feet away, termed pyramids by Wilkes, were about twelve feet in diameter and from twelve to fifteen feet high. These were said to represent the districts of the island.

It remained for a later king to erect a more lasting memorial, the famous City of Refuge, at Honaunau, Kona, Hawaii, which, while credited to Kanuha in memory of one of the Keawe's, may properly have been built by Keawenui, about the year 1570. In form it is an irregular parallelogram, walled up on one side and at both ends, the other side being the sea shore. An early visitor described this enclosure as 715 feet in length and 404 feet in width, with walls twelve feet high and fifteen feet thick, in which were holes about four rods apart where large images had formerly stood. Within this enclosure were

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three heiaus, two of which were in bad repair, while the third was nearly entire, a compact pile of stones built up in a solid mass, 126 feet by 65 feet, and ten feet high. Many pieces of lava rock, of two or more tons each, were seen in several parts of the wall, raised at least six feet from the ground. There are also the Keoua and Kaahumanu stones, both of immense size, of squared form, near the lower temple. The whole premises have recently been put in order for preservation, and careful study is being made of their construction features.

Mention has been made of the dissimilarity of the heiaus throughout the islands. This is true especially of the internal plan. Malo and Kamakau list the heiaus as of four or more in kind or rank, but unfortunately their descriptions and statements of the purpose for which the temples were built are vague, and in some cases conflicting.

The most important heiaus were termed luakini, a class belonging to the king only, that is, erected by his order, to aid in war or to celebrate a victory. They were usually dedicated with one or more human sacrifices; hence we find the term *pookanaka* (man's head) applied to all temples of the luakini class.

The next grade of heiau, while belonging to the king, could also be built by the chiefs. These temples were known as *waihau*, and *unu*, and the offerings consisted of pigs, bananas and coconuts. The term unu has often been found applied to heiaus of the severe, human sacrifice class, which leads to the supposition that it refers to the structure as of platform rather than the walled type, instead of indicating a class of service.

Next in grade were the temples of the common people, of which there were several kinds for the farmers, the fishermen (Koas), and others. Hence the wide range in size from twenty feet square to several hundred. This however does not explain the diversity of shapes in those of the same class, and leaves us unfortunately in ignorance on important points of temple structure, and ceremonies attending the ancient worship of Hawaiians.

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ANTHROPOLOGY OF THE PHILIPPINES

By A. L. Kroeber

I heartily endorse everything Dr. Wissler has said about anthropological method. I think it can be said to-day with complete fairness that there definitely exists such a method, which is as clearly applicable to the human problems of race and culture, as is the respective case for geology and botany. Just as no student of these sciences would assume to solve problems of the earth's crust or of the origin of plants by other than by geological or biological means, so no modern anthropologists would attempt questions of race origins or developments of civilization by any but his specific method. Dr. Wissler has covered this ground so well that I prefer not to dilate upon his point of view, but rather to give some of the results of this method as they have been worked out for a particular area—the Philippine Islands.

The Philippines lie on the border of the Pacific, as Hawaii is near the center. The two groups form part of the same general area, and further are connected in an ultimate relationship. The precise degree of this relationship remains to be ascertained, but the two archipelagos show a similarity probably in race, certainly in language, and very likely in culture. Consequently there seems some promise, if we apply to the problems of Hawaii and Polynesia proper the methods of attack which have yielded at least preliminary results in this related area at the fringe of the Pacific, that valid inferences can be obtained here also without undue difficulty.

The situation in the Philippines is this. There are, besides immigrants of recent centuries, three race elements of distinct origin. The earliest of these are the Negritos, a race of dwarf black people with broad noses, black skins, woolly hair, protruding jaws—in fact, Negroid in every respect except stature. In this trait their average is barely five feet, far below almost all races of mankind. According to every indication, the Negritos were the first occupants of the Philippines.

Later came a race of brown people: early Malayans or Proto-Malays, some authors have called them; Indonesians is another name for them. They came presumably from the west; possibly from Asia. They encountered the more primitive

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blacks, assimilated or exterminated them in the smaller islands, and drove them back to the interior of the larger ones, into the security of the central mountains, whereas they themselves occupied the fertile lowlands.

The third populational strain consists of a race closely allied to the Malays and Javanese, and whom we may call the Malayans proper. They were brown-skinned and lank-haired, rather similar to the Proto-Malayans or Indonesians and almost certainly related to them. But the Proto-Malayans or Indonesians are shorter statured, broader nosed, and longer headed—sufficiently different to enable us to distinguish these two brown races. Now the later Malayans took much the same historical attitude toward the Proto-Malayans that these had taken toward their predecessors, the Negritos. They may have been more or less numerous, but they certainly possessed superior arts and a more advanced culture. Thus they drove the Proto-Malayans inland. The result is that in the larger islands, where aboriginal conditions are best preserved, we find the race map disposed much like a target. The bull's eye is a little group of Negritos in the inaccessible mountains. Surrounding them is a ring of Proto-Malayans, more civilized than the Negritos, but less so than the Malayan coast people. These in turn form the outer circle, holding the best of the land along the shore and in the plains. Such is an outline of the salient facts as regards race.

The language situation is very much simpler on its face, but in a way perplexing too. All three races now speak what are only dialects, surface varieties as it were, of one fundamental tongue. Now the Negritos must once have had a language of their own; and, the two brown racial elements having been separated long enough to develop the physical differences referred to, we might expect that they would have been differentiated also in speech. Yet, strangely enough, no such basic division is apparent. The difference between the dialects of Proto-Malayans and later Malayans is often no greater than that between two Proto-Malayan or two later Malayan groups. As regards the Negritos, it must be that because of their numerical and cultured inferiority they have gradually given up their old tongue and adopted that of the more powerful brown peoples surrounding them.

When we come to culture, in other words the arts, customs, institutions, religion, that whole body of human knowledge that

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makes up the civilization or mode of life of peoples, we find conditions more complex than either in race or language. As we review the many nationalities of the islands we can trace at least half a dozen groups of factors that have gone into the building up of their culture. We can even proceed as a geologist would, beginning with the latest and working backward in time to the earliest, discovering so many strata of deposition, as it were.

The first or topmost of these cultural layers is that due to the Spaniards, who introduced, to the majority of the natives at least, Christianity, coherent political institutions patterned on those of Europe, the Roman alphabet, trade, many new arts, and certain food plants, notably maize and perhaps camotes. This Caucasian civilization is so well known to us that we may pass it by to penetrate to the others that underlie it.

Not quite two hundred years before the Spaniards reached the Philippines, the Mohammedans had come. These may have included some Arabs, but consisted chiefly of Malays who had been converted to Islam. Wherever these Mohammedians obtained a foothold, they established little kingdoms or sultanates, introduced new laws, brought in Mohammedanism, and in connection with it the Koran and Arabic script. They also introduced firearms. In many other respects they did not work very material changes because they were themselves rather thinly veneered with Mohammedan civilization. Also, being conquerors few in number, they were not particularly concerned in changing the mode of life of their subjects, but left them free to remain as they wished as long as they paid tribute. Further, the Mohammedan conquests and conversions never extended much beyond the southern part of the islands.

Preceding this Islamic one, there was a much more important wave of civilizational influence: on the whole, the most important of the several that have reached the Philippines. It emanated from India, and involved religion, knowledge, and many arts. These elements of culture were probably not carried to the Philippines by the Hindus themselves, but imported from Java, or other East Indian islands, where a strong Hindu influence began to be established about two thousand years ago. Brahminism as such seems never to have been introduced into the Philippines, but any number of its ideas and forms did reach the archipelago; and with them many words of the Sanskrit

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language, and the first system of writing—not yet wholly gone out of use—to be employed by any Philippine peoples. Of inventions, the technique of iron working is probably the most significant.

There is another group of culture elements that can be definitely traced to the outside: those of Chinese origin. China lies nearer the Philippines than does India, and its civilization was equally ancient and advanced. Chinese ships are known to have reached the archipelago some seven hundred years ago and may have visited it long before. Yet, it is illustrative of the temper of the two nationalities that whereas the Hindus gave liberally of their civilization, particularly on the religious and spiritual side, the Chinese chiefly brought in trade articles. To-day some of the interior mountain tribes possess jars manufactured in China some four to six hundred years ago. Certain of these half-naked Igorote "savages," who from our point of view are almost poverty stricken, treasure these heirlooms so that they will not sell them for thousands of dollars. But aside from such objects and possibly some manufacturing processes, the Chinese seem to have given little or nothing to Philippine culture.

Before the Hindus and Chinese came there must of course have been something of a native culture; although at present most of what we know about it is through the process of subtracting everything that we know to be European, Mohammedan, Hindu, or Chinese. What is left we find to be a type of culture that in its general aspects is not so very different from that of Polynesia at the time of discovery. I do not mean to say that the Polynesians came from the Philippines, but that the native cultures seem to have something in common. To mention only one point, there is the status of woman. Women were more nearly on a level with men in Polynesia than in any primitive society beyond the Pacific ocean. This shows in kinship reckoning, inheritance, marriage laws, and many other ways. Now in this fifth from the top of the strata of Philippine culture—which is apparently best preserved among some of the Proto-Malays of Luzon—we find almost exactly the same conditions prevailing. Where this status no longer prevails in the Philippines, we can virtually prove it to have been lost under the influence of the Hindus, Mohammedans, and Spaniards.

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Back of all the above there must have existed a very simple culture of the Negrito. But he has apparently done very much as in the matter of language, that is, borrowed parasitically and incompletely from the more numerous and advanced peoples around him. It is entirely possible, however, that with more exact ethnological data we may yet be able to reconstruct something of this most primitive or Negrito stratum of Philippine culture.

Now, on reviewing these results, we find this situation: There are in this one group of islands three recognizable racial elements, a single parent language, and at least six different streams of culture. This emphasizes a lesson that anthropologists have been taught by force of necessity time and again, namely, that to argue from the physical heredity or blood of a people to their language or culture, or reversely to infer a dissimilarity of racial origins from a diversity of customs or speech, is one of the most risky and misleading things that can be done in science.

When we apply our Philippine determinations specifically to Polynesia, we find that probably both the brown races of the Philippines and the Polynesians are related in physical type: how closely, it is not yet possible to affirm, and yet the basic fact is scarcely to be doubted. As regards language, the studies made during a whole century have shown conclusively that relationship is close. In the complex domain of culture, knowledge is still too little systematized for any opinion to be worth much: but features such as the position of women that has been referred to indicate much. Besides, it is possible that certain elements of Polynesian thought may prove to be a locally remade radiation of East Indian civilization after this had begun to undergo Hindu influence. Mythology is especially suggestive in this regard.

There is one caution that I should like to utter. If the problem of man in the Philippines had been approached wholly from a Philippine standpoint, without reference to the rest of the world, it is obvious how confused the results of Philippine anthropology would be. It is by segregating Christian, Mohammedan, Hindu, Chinese, later Malayan, and early Malayan elements, that the history of what happened in this one group of islands can be unraveled in outline instead of remaining a jumble without perspective. It is through the assumption that there is

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no Philippine problem pure and simple, but that the history of man in the group is only part of his history over much wider areas, that analysis is possible which carries us back to India, Babylonia, Arabia, and allows a reconstruction that is founded in fact instead of merely speculative. Now we must know Polynesia before we can understand it; but, once having the facts, we can no more explain them on a purely Polynesian basis than we can in the Philippines. It is outlook that counts, and interrelations. But with this precaution observed, and a strict adherence to the analytic comparative method before any theories are propounded, the mystery-shrouded questions as to the whence and when of the Polynesians, as to the source of their strangely barbaric and yet refined civilization, are surely answerable.

COMMENT BY MR. SAFFORD

I lived for a year on Guam, an island which might be called a stepping stone between Hawaii and the Philippines. The ancient culture of its inhabitants may be considered intermediate between the culture of the Polynesians and certain mountain tribes of the Philippines. Students of Polynesia are familiar with the laws by which the words of the various dialects are interchanged. In studying the language of the Easter Islanders more than thirty years ago, I found that there was a regular system like a Grimm's law by which every Easter Island word could be changed to a Hawaiian word. Later I found that this applied almost equally well to the Samoan and Maori languages. Still later I discovered resemblances not so apparent between the language of the aboriginal inhabitants of Guam and the Polynesian dialects. In many cases the identity of the words was concealed by terminal consonants or by reduplication; and many Spanish words have been adopted in the modern language of the island. The Polynesian *ala*, road, becomes *chalan* in the Chamorro language of Guam, and *djalan* in Malayan, *i'a*, or *ika*, fish, becomes *guihan; ahi*, or *afi*, fire, becomes *guafi; mai*, the directive particle "hither", and *aku*, or *atu*, "hence", or away from the speaker, become *magi* and *guatu*. The inclusive and exclusive plurals of the first person pronoun correspond with the Polynesian, but in the language of Guam there is no dual number. Many of the words are obscured by reduplication and infixes and by the modification of the vowel of the tonic syllable. Thus *kolat*, fence, derived from the Spanish *corral*, when pre-

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ceded by the definite article becomes *i kelat*. and *resibe*, from the Spanish word for "receive" by reduplication becomes *resisibe*, and by the infixing of *um*, *rumesibe*.

In these features the language of Guam resembles the various languages of the Philippine Islands, and the culture of the aboriginal inhabitants was very similar to that of the modern Igorotes of Luzon. They had the same belief in *aniti*, or spirits, the same system of cutting off the heads of the dead and keeping them in baskets in their homes. Indeed when they fancied they saw ghosts in the woods or fishing on the reefs they declared that these were headless. They also had the great houses in which bachelors lived.

Indeed the Philippine area should be extended eastward to include the Marianne Islands, and in my opinion there should be four instead of three elements recognized in Malayo-Polynesian ethnology: (1) the Proto-Malayan, whence the true Polynesians came, bringing with them the 'ava plant (*Piper Methysticum*), *the taro* (*Caladium esculentum*) from which poi is made, and the paper mulberry, from which kapa, or tapa, is made; (2) the element having the culture of the Igorotes of the Philippines from which the aboriginal inhabitants of Guam came, not leaving their ancient home until after the introduction of rice and the betel pepper (*Piper betel*) from India; (3) the lowland tribes corresponding to the ancestors of the Tagalogs and Visayans and (4) the modern Filipinos. It is interesting to note the absence of any Indian or Mohammedan influence upon the culture of the Guam aborigines, which indicates the relative time of their departure from the cradle of their race.

In conclusion I wish to express my appreciation of all that Dr. Wissler has said. It is methods pursued by him that lead to ultimate success in solving ethnological problems.

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ANTHROPOLOGY IN JAPAN, NEW ZEALAND, AUSTRALIA AND THE PHILIPPINES

NOTE:—The following information as to institutions and activities of anthropologists in Japan and New Zealand is abstracted from the Proceedings of the Pan-Pacific Scientific Congress held in Honolulu, August, 1920. The review of the status of anthropology in New Zealand was prepared by H. D. Skinner, Lecturer in Ethnology in the University of Otago; for Japan by N. Yamasaki, Professor of Geography in Tokyo Imperial University; for Australia by Frederick Wood-Jones, Professor of Anatomy in the University of Adelaide. The statement for the Philippines is compiled from the stenographic report of remarks by Elmer D. Merrill, Director, Bureau of Science, Manila.

NEW ZEALAND

In the field of Osteology a large number of measurements have been recorded in different scientific journals, but the only work on any considerable amount of material is that of the late Professor J. H. Scott, who gives measurements of eighty-three skulls, and of a much smaller number of body and limb bones. In the thirty years which have passed since Professor Scott's research, a large amount of osteological material has been collected, especially in the Anatomical Museum of the University of Otago, but no attempt has been made to work it up.

The only work on the bodily measurements of living subjects is that recently undertaken by Dr. Peter Buck, himself of Maori descent. This research promises to be of the very highest importance.

In Sociology the outstanding work is that of Mr. Elsdon Best, who, coming late into the field, has far surpassed all other workers in the volume and value of the material he has collected. There is still scope for intensive work among the tribes not touched by Mr. Best, especially those of the Taranaki and Whanganui district, and of the peninsula north of Auckland. Mr. H. Beattie has recently collected with unexpected success among the scattered remnant of Maori on South Island. Mr. S. Percy Smith, doyen of New Zealand anthropologists, has recorded an amount of traditional material unequaled by any other worker in the Pacific, but it is unlikely that any considerable amount of new traditional material will become available in the future.

In the field of linguistics, three generations of the Williams family are preeminent, and no great advance in amount at any

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rate, is likely to be made on the fourth edition of the Maori Dictionary, edited by Archdeacon Herbert Williams. There remains, however, much work to be done on Maori dialects, for which research a good deal of material is still available in the spoken language and in manuscript in libraries and private hands. The importance of work in this field is indicated by the fact that the phonetics of the Kai-tahu dialect differ from the phonetics of dictionary Maori more than do the phonetics of Easter Island. The collection of phonographic records of songs and speeches has been begun by Mr. J. McDonald of the Dominion Museum.

Though in the field of material culture, as elsewhere, material is rapidly disappearing, a great amount of profitable collecting may still be done by the right kind of worker. Almost any middle-aged Maori can give information never before recorded regarding fishing, fowling, and similar aspects of the life of his tribe. Considering the inherent attractiveness of this kind of material and the excellence of Maori craftsmanship and decorative art, it is remarkable that so little information about it has been collected. Outstanding researches are those of Mr. Best on the working of stone, of Dr. Buck on weaving, of Archdeacon Williams on the Maori house, and of Mr. Downes on eeling. Mr. Anderson's record of string games should also be noted.

Work in the past has been sporadic and of varying quality. The chief encouragement to research has been the existence of the Polynesian Society which, through its journal, edited for thirty years by Mr. Percy Smith, has guaranteed the rapid publication of original work. The same function has been performed, but to a lesser degree, by the New Zealand Institute, through its *Transactions*, and during the past three years by the *New Zealand Journal of Science and Technology*.

The institution by the University of New Zealand of a Certificate in Anthropology has been followed by the appointment of a lecturer in ethnology in the University of Otago, and it is hoped that the three remaining colleges affiliated with the University of New Zealand will also undertake the teaching of the subject. The University of Otago has supported field-workers for brief terms among the South Island Maori and at the Chatham Islands. The New Zealand Institute has also aided the former work.

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Only one museum has thus far carried out anthropological work on any scale. Members of the staff of the Dominion Museum have in recent years made some of the most notable of all contributions to the study of Maori ethnology. Other museums have confined their activities to making ethnographic collections, but there is now a reasonable prospect of some of them taking up field-work of other kinds.

The New Zealand Institute makes grants to research workers.

From this brief survey it will be seen that sporadic work by individuals is slowly yielding to systematic work by three classes of institutions: the university colleges, the museums, and the New Zealand Institute. The intensification of work by all three is prevented solely by lack of funds.

Nothing has been said in this report about field-work in the New Zealand dependencies in the Pacific. Our obligations in this regard are obvious.

JAPAN

The Anthropological Institute and professorship of anthropology in the College of Science in the Imperial University of Tokyo were established in 1892. From that year until 1912, Dr. S. Tsuboi was professor of anthropology, but since that date the position has been vacant. However, there are two lecturers: R. Torii, S. Ishida. The rich collections of anthropological, ethnological, and archaeological specimens from all parts of Japan, China, Mongolia, Manchuria, the South Sea Islands, etc., are in charge of the curator, A. Matsumura. The reports of the principal explorations conducted have been published in the *Journal of the College of Science*, in English or French. Reports on Formosa, China, Mongolia, Manchuria, and the Kurile Islands have been published by R. Torii and on the Caroline Islands by A. Matsumura.

In the College of Literature, S. Harada is the lecturer in archaeology.

At the Imperial University of Kyoto there is no chair of anthropology, but B. Adachi, professor of anatomy, is a lecturer, and K. Hamada, is professor of archaeology. Prof. Hamada has published the following in English: Stone Age Relics of Ko, Ancient Caves in Higo, etc.

No professorship in anthropology is maintained at the Imperial University of Sendai, but the College of Science has a pro-

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fessor of anatomy, K. Hasebe. H. Matsumoto is lecturer in anthropology. The College has many good collections from northern Japan, while a great shell-heap on an island of the Matsushima group is reserved for study.

In the department of history of the Imperial Museum of Tokyo there are excellent collections, in charge of the department director, Prof. Y. Miyake; the curator and his assistants are: K. Takahashi, Wada, and Goto.

The Anthropological Society of Tokyo was established in 1886. Its present membership is 313. The Society meets monthly at the Anthropological Institute of the Imperial University, except during July and August. It has published since its organization thirty-five volumes, in 394 numbers, of the Journal of the Tokyo Anthropological Society. The presidency is vacant; there are twenty councilors, whose acting director is Prof. R. Koganai; the secretaries are R. Torri, S. Ishida, and A. Matsumura.

AUSTRALIA

Australia has no federal bureau nor any institution in any individual state that maintains a properly staffed and equipped department for the conduct of anthropological work.

The establishment of a chair of anthropology in one of the large universities having teachers and research facilities is a greatly needed desideratum. The present writer feels very strongly that plenty of competent young men would be ready to take up the work were a chair of anthropology established in one or more Australian universities. It is hoped that the deliberations of the Congress will serve as a stimulus to the Australian delegates and enable them to influence public and official opinion in Australia and so lead to the establishment of a chair of anthropology in one of the universities of Australia.

In the museums of Perth, Adelaide, Melbourne, and Sydney there is a large amount of anthropological material, both physical and cultural, which should be worked over along modern scientific lines. More especially is this want felt in regard to the examination of the skeletal remains of the peoples of Australia and the surrounding Pacific regions.

The museums mentioned above are not directly attached to the universities and it is much to be desired, pending establishment of a chair in anthropology, that coördination of effort be brought about by the appointment of university teachers inter-

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ested in anthropology as honorary curators of anthropology in the museum. A large amount of anthropological material is in the hands of private collectors in Australia; this private appropriation, especially of large series of crania, should be emphatically discouraged.

THE PHILIPPINE ISLANDS

The Philippines include three racial types, Negrito, Indonesia and Malay, and more than forty languages are represented. Government support for anthropological work in the islands was at first given to the Bureau of Non-Christian Tribes and later to the Division of Ethnology of the Bureau of Science. Recently official support was withdrawn by the legislature which questioned the propriety of publishing photographs illustrating primitive customs. Valuable research is now being carried on privately by Professor H. Otley Beyer, Associate Professor of Anthropology, University of the Philippines, who has prepared a comprehensive "Outline of a Proposed Ethnographic Survey of the Philippine Islands." [This outline read by Mr. Merrill in the form of an official communication is not available for publication.]

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RECOMMENDATIONS FOR ANTHROPOLOGICAL RESEARCH IN POLYNESIA

PREPARED UNDER THE DIRECTION OF THE SECTION OF ANTHROPOLOGY, FIRST PAN-PACIFIC SCIENTIFIC CONFERENCE

NOTE: The Section for Anthropology of the First Pan-Pacific Scientific Conference found it impossible to complete the formulation of a research program before the date of adjournment. Accordingly, it voted to request the National Research Council of the United States to undertake the final formulation of its report. The Research Council accepted this obligation, referring it to the Division of Anthropology and Psychology by which the undertaking was brought to a conclusion.

In the preparation of this report the following contributors and members of the Council have taken part:

Roland B. Dixon, Harvard University; Gerard Fowke, Bureau of American Ethnology, Washington; A. E. Jenks, University of Minnesota; A. L. Kroeber, University of California; R. H. Lowie, American Museum of Natural History; W. H. R. Rivers, St. Johns College, Cambridge, England; L. R. Sullivan, American Museum of Natural History and Bishop Museum; L. M. Terman, Leland Stanford University; J. Allan Thomson, Dominion Museum, New Zealand; Thomas G. Thrum, Bishop Museum, Honolulu; A. M. Tozzer, Harvard University; Frederick Wood-Jones, University of Adelaide; N. Yamasaki, Tokyo Imperial University.

INTRODUCTION

Anthropological research in the area of the Pacific is still in the formative stage, having just passed through the necessary period of preliminary exploration and superficial surveys. The area is a large one, which for practical reasons we may consider under the following heads:

- I. Insular Areas
  1. Polynesia
  2. Micronesia
  3. Melanesia
- II. Continental Areas
  1. The Philippines and the Malay Islands
  2. New Guinea
  3. Australia

Research in all of those areas is of great importance, but we consider the Polynesian problem as the immediate primary undertaking, since Polynesia comprises the heart of the Pacific, and particularly because this area is now about to become the field of operation by the Bernice Pauahi

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Bishop Museum in Hawaii. While this institution has projected immediate field-work upon an extensive scale the problem is, nevertheless, a complicated one, whose ultimate solution must depend upon collateral work in all parts of the Pacific. For this reason, some kind of cooperative research is absolutely necessary and it seems in keeping with the spirit of this conference that all institutions and individuals working in this area, should, as far as possible, cooperate to the extent that all results of field-work may be of the greatest service. It is with a view to facilitate such cooperation that this outline of scope and methods, which in our judgment best apply to Polynesia, has been formulated.

I. STATUS OF ANTHROPOLOGY IN POLYNESIA

Anthropological study of the quality and character which has been exemplified with such gratifying results in other parts of the world during the last two generations, has for Polynesia hardly yet begun. The greater part of the data at present available has been gathered by untrained observers and in an unsystematic manner. For some portions of the area, relatively abundant material of this sort exists; for others, there is little or nothing. The following brief survey of the status of our knowledge may serve to show the character of information needed to enable us to work out the problems which the area presents.

Physical Anthropology

Cranial and skeletal data. Only for Hawaii, New Zealand, and Easter Island is any reasonably adequate material available. For the first two, much more extensive regional collections are much needed, however. For the Marquesas, Paumotu, Society, Cook, and Austral groups, the existing data are meager and need to be largely increased, with special attention to securing well authenticated material from the various separate islands in each group. For Samoa, Tonga and the scattered and isolated islands, there is practically no material at all.

Measurements of the living. Except for a small number of scattered observations, no data at all are available.

Material Culture

The fullest data are from Hawaii, New Zealand, Chatham Island, and Samoa. Little or nothing in the way of systematic investigation has been made elsewhere.

Social Organization

Little investigation of the modern sort has been made as yet anywhere. For Samoa, Tonga, Society, and Hawaii, we have considerable more or less undigested material in the older literature, but many important sides of the question are as yet untouched.

Religion

The fullest material available is from New Zealand and Hawaii, from both of which much ceremonial and mythological data have been collected. For Samoa, Tonga, and Society we have some material on the ceremonial side, but it greatly needs amplification. For the Marquesas, Paumotu, Cook and Austral groups the existing data are very meager.

Linguistics

Lexical, grammatical, and biblical text materials are in print from practically all the Polynesian dialects and languages. What is most needed at present is a more adequate knowledge of the etails of phonetics, and a collection of native texts of mythological or her nature, to supplement the missionary material already available.

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II. PROBLEMS TO BE EMPHASIZED IN THE POLYNESIAN AREA

The following statements and recommendations should not be taken as an attempt to present a complete, well balanced outline, applicable equally to all parts of Polynesia, but as a sketch of the problems which from the present state of our knowledge should be stressed. Recognizing that the collection of full data from even a single group of people, is a task of huge proportions and that there are subjects and occasions where those with little experience may have opportunities for observation denied the professional investigator, we have included some of the less obvious cautions. Naturally, each investigator must carefully analyze the local conditions about him and adjust his program accordingly. Further, since the field of anthropological research is so vast and complex, that one must perforce specialize in some small part of it, each investigator must depend upon others for specific suggestions as to what is important from their points of view.

1. ETHNOLOGICAL RESEARCH

At the outset we recognize that for practical reasons the investigations under this head must be pursued by the group (or tribal) method rather than by the topical. In the usual course of events, the field-worker first acquires some knowledge of the language of the group he visits and then systematically collects data on all the obvious phases of culture manifest therein. According to his inclination, he may specialize more or less upon the different phases of culture. The time required to cover the whole subject of culture even in this unsymmetrical way is quite considerable and in most cases prohibitive, so that what usually happens is that the field-worker concentrates upon one or more of the large divisions of culture. Linguistics and music, because of their highly technical nature, are most frequently left for a single investigator, but not infrequently the line of further specialization falls between material culture and the less material traits. Further specialization is possible, but in our opinion not compatible with the best results. Taking in consideration the distances to be traveled, the inaccessibility of many islands, etc., we recommend that expeditions be so planned that two men can handle the whole of archaeology and ethnology, exclusive of linguistics.

A. MATERIAL CULTURE AND ART

In material culture, especially, the most approved method is to deal with what are called complexes. For example, the investigation of fishing is the study of a complex, including the mechanical technique of the art, practical knowledge, social position of the fisherman, the beliefs controlling fishing, and the ritual and religious sanctions upon which the natives believe the whole to be grounded. The ideal of the investigator should be to follow out completely all the most important complexes functioning in the group he investigates. Naturally some complexes are of more importance than others; thus, in the study of a Polynesian group, the following should be stressed:

Fishing and marine foraging
Agriculture and domestication
Canoe building
Tapa, textiles, and feather-work
Work in wood and gourd
House, temple and other building.

It goes without saying that in the end nothing should be overlooked, but since it is rarely possible to carry a unit of field-work to such a

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conclusion, one should make sure of covering fully the groups of complexes just enumerated.

Further, it is well to bear in mind that we have in some parts of Polynesia, at least, a high development of the artisan cult with definite religious sanctions; hence, this should be made a special topic of inquiry.

Attention should be given to such specific traits of culture as have distributions in other parts of the world. Thus, the use of stilts was once reported by K. von den Steinen for the Marquesas. In all probability they have now disappeared everywhere in the islands, but it would be well to inquire in different localities whether, how, and for what purpose they were formerly employed, especially whether in pantomimes or dramatic performances, as in some contiguous parts of the Old World. In the same way evidences of the kite and all its forms and uses should be carefully sought.

While, as stated under the head of language, the worker in culture is not to be expected to collect language data, it is important that he acquire some familiarity with the speech of his informants and exercise care in recording the native names for all important phases of the several complexes.

One caution, applying to all sections of this report, should be noted. No topic enumerated here should be taken up in the abstract and the investigation guided solely by the associated concepts. Thus, the topic *fishing* does not mean that fishing, as such, is the object for investigation, but that the problem is to find out how specific fish are caught, how a given fisherman prepared for fishing, etc. The formulation of abstractions may be left to the future; they have no real place in field-work where concrete fishing processes should be the subject of investigation.

In most parts of the world, data on material cultures have an intimate relation to those resulting from archaeological inquiry. The relative dearth of stone objects in Polynesia tends to weaken the association, but there is partial compensation in the homogeneity of the historic and prehistoric cultures of the area. When a people have become extinct or greatly modified in culture, data concerning them tend to become materially objective, so that the remains of material cultures and art often form the sole basis for the reconstruction of the past. Hence, in Polynesia it seems inadvisable to separate those subjects (material culture, art, and archaeology) in field-work.

Navigation. Special attention should be given to this topic, that is, to the gathering of data bearing upon the technique of navigation. One of the crucial problems in the spread of the Polynesian is his mode of navigation. Very little good data have been collected and no doubt much has been lost, but its importance demands the greatest diligence on the part of the field-collector. Astronomical, geographical, and meteorological lore should receive the closest attention in this connection. The mystery that now hangs over the voyages of the Polynesians is merely one of ignorance; that they did reach the distant islands we know; hence, it follows that they had a technique of navigation commensurate with the result. The problem now before us is to secure as much of this technique as is still known to the Polynesians now living.

Museum Collections. The day of profitable collecting among the Polynesians has passed, but every field-worker should comb over his territory to make sure that nothing remains. No doubt many homely utensils and ornaments survive particularly in the out-of-the-way places. Also many rare things may be found in private collections where they may be studied to advantage.

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The collection of models and restorations is advisable. A native model may be crudely made, but it has value to the field-worker gathering data upon the complex in which it is found. Every possible means should be taken to objectify the data upon culture traits.

Use of Photographs. The field-worker should study the collections in our museums from the group he is to visit. He should be equipped with photographs and drawings of all typical objects—prints from line drawings are usually better, as the natives can interpret them much more readily. As far as possible, the objects represented should be identified by informants and the existing data as to their functions recorded. Such a collection of drawings will be of great service in holding the interest of informants.

Most of our museum collections are without data of any kind, so that the use of this method may greatly enrich our knowledge and make these collections of much greater value.

Art. Collections in museums have made us familiar with the chief characteristics of Polynesian art. It is to these collections we must now go, because little of a satisfactory character remains in the hands of the natives. As these collections are in safe keeping, their study may be left for the next generation; but some aspects of the subject should receive immediate attention. Photographs and drawings of tapa, tattooing, and carved patterns should be taken to the field and information concerning them sought from the old people.

A subject worth recording is the adjustment now being made to our own decorative art. Data and collections showing the mechanisms of this adaptation will be of value in the future.

Ethno-zoology. In Polynesia the origins for the varieties of domestic animals and plants are of unusual importance, since the history of these varieties will be, in the main, the history of the human fauna. These biological problems are, however, intricately bound up with those of the domestic fauna and flora of the world as a whole. Thus the investigation of the pig, chicken, and dog in Polynesia will require the thorough study of the history of domestication for these animals in the world at large. Each of these topics is sufficient to occupy the spare time of an investigator for many years, but in our opinion they are best handled as side lines for enthusiasts. In the meantime, however, some special collections of material and data from the several islands are desirable. Such material will be of great value to future investigators and should be given some attention by all field-workers.

Since ethno-botany has received special treatment by the Botanical Section of this congress, the reader is referred to that portion of the report. However, we wish to stress the importance of these investigations and to urge that close attention be given to the domestic species usually neglected by botanists.

Exact data regarding the distribution and importance of the cultivated plants introduced from America are required for all islands. The data available are exceedingly vague and meager and leave important points unanswered. It is not sufficient to note, e.g., that maize is cultivated in a certain region; we want to know what variety or varieties (all the different corncobs from each locality should be collected), whether merely as a garden plant or in fields, whether alone or together with other crops (e.g., beans), process of the cultivation, what importance attaches to it in the native household, how the corn is utilized, how it is ground, prepared, cooked, etc., what the people think about its usefulness, traditions regarding introduction, etc. Careful inquiries should be

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made as to tobacco, method of preparation and consumption (cigar, pipe, chewing, snuff). Indigenous species of Nicotiana are reported from Australia (*N. suaveolens*), New Guinea (species unknown), and Norfolk Islands (*N. fragrans*); some suppose, although on insufficient evidence, that tobacco was anciently used in those regions before European contact. If so, was there any prehistoric trade in tobacco in the South Sea? Possibly one or other of the species named or other species of Nicotiana may be discovered in Polynesia. At any rate, it may be worth while to search or inquire. Careful observations should be made concerning manioc, arrowroot, the various species of Phaseolus, Capsicum, gourds, potato, sweet potato, peanut, pineapple, guava, papaya, tomato, sunflower, etc.

Of plants native or supposed to be native, special attention should be devoted to coconut, banana, *Broussonetia papyrifera, Coix lacryma* (Job's tears), and all species of Dioscorea. Uninhabited localities where coconuts grow should be carefully mapped. The numerous varieties of banana should be noted.

The distribution of domestic swine and the whole economy connected with it appear to be one of the fundamental problems in Polynesia. Note whether white and so-called masked pigs occur, observe and describe the different breeds and crossings, collect skulls of wild, domestic and half-wild ones (which have escaped from domestication to live for themselves in the wilderness).

B. MYTHOLOGY AND RELIGION

Mythology. The mythology of Polynesia has for many years attracted the interest of scholars, yet except for New Zealand and Hawaii, no extensive collection of material has been made. Although from these two groups and especially from the former, a large body of data is in existence, there has been even in these cases, little attempt to make the collection really systematic. For other parts of Polynesia the material is in general very meager, and every endeavor should be made to gather what survives before it is too late.

Local variants within island groups and even within single islands should be carefully sought for. The importance of such variants has long been recognized, but their value in the Polynesian area is probably more than ordinarily great. The cosmological side of Polynesian mythology has always attracted the most attention, but much additional material of this kind will be needed to make it possible to make clear the development of the peculiar system and trace its origins. Another point to receive consideration is the distinction frequently made between the mythology current among the aristocracy in contrast to that of the common people.

When so much material needs to be gathered, it is rather invidious to mention particular groups as requiring special attention, but it would seem that the Marquesas and Paumotu, the Austral group, and the Ellice and other small islands in the western portion of Polynesia might be singled out as being at present least known.

Religion. In the pursuit of this topic the less experienced worker cannot too often be reminded that he is to study religion as a concrete function and not as an abstraction. Thus, in Polynesia the burial complex is important under this head, but it should be dealt with as a reality and described with great fidelity of detail. Religion, apart from culture activities, tends to become the subject matter of philosophy rather than of science; hence, inquiry into religion will center in the study of specific complexes in which superhuma sanction and ritualistic control are plainly present. In such

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interpretation the precise definition of religion is unimportant, since concrete activities are the objects of observation.

Some of the other complexes for which the fullest possible data should be sought, are:

a. Shamanistic practices. All kinds of magic should be recorded, not overlooking the more widely diffused folk magic.
b. Doctors. Concrete facts bearing upon the relations of this function to that of shamanism should be sought as well as upon the technique of medical practice. In both this and the preceding careful inquiry should be made as to the ideals, training, social distinction, etc., pertaining to these professions.
c. Priesthood. In at least some parts of Polynesia, a highly organized priesthood has been observed, with temple observances. This should be made a subject of exhaustive inquiry. Particular attention should be given to the relative importance and functions of official or public priests, family-head priests, heralds or assistants, women associates, seers, shamans, etc., in the group. Ritualism is another important phase of the priestly function and one concerning which new data are needed. Rituals may be almost too simple to attract attention but may also be elaborate. The types should be sought and examples of each recorded as fully as possible. Attention should also be given to the use of genealogies as religious formulae. Finally, the priestly practices concerning sacred groves, caves, seats, etc., should be studied.
d. The investigation of special cults. Fertilization cults; agricultural rites, ancestral cults, animal cults. Seasonal factor in ceremonials.
e. The taboo. This is one of the most important aspects of Polynesian culture and one whose general characteristics are known; but the available data often do not form a clear picture of the working of the taboo and the involved psychological attributes remain ambiguous. For this reason careful investigation of the specific taboo systems for the islands visited promises to be valuable.
f. Cannibalism, head hunting, war dances, etc.
g. Ideals of souls, spirits, death, and cosmology. Systems of heavenly strata should be enquired for, likewise a hades. Distinctions between the souls of men and other objects may appear and prove of comparative value, also beliefs on transformation, incarnation, etc. Concrete data under this head will for the most part be limited to statements of individuals as to their opinions and beliefs.

The opinion is often freely expressed that all the correct knowledge of these subjects has vanished from Polynesia. Experience in other fields has shown that when language survives a surprising amount of data can be secured. We can state, therefore, with reasonable certainty, that even in Hawaii and New Zealand, a competent investigator will find no dearth of important data. On the other hand, each year is diminishing the available data and rendering the collection of what remains more difficult and more expensive.

The preparation of manuscripts by native Polynesians should be encouraged in every possible way. An effort should be made to collect frank and full autobiographies of old men and women. The skilful use of this method has brought such important results in other fields that it is now being recognized as one of the most productive procedures. The value of these narratives, lies not in the personal adventures of the nar-

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rators, but in the circumstantial settings to these adventures in which are to be found vivid portraits of everyday social routine. For example, a good story of a fishing excursion or a courting adventure may be highly exaggerated as to plot, but will, in its setting, give the plain, essential details of native life.

C. SOCIAL ORGANIZATION

The investigation of social organization presents certain inherent difficulties and thus warrants a more detailed statement than has been accorded other topics in this series. The following outline will also make possible concrete observations by such casual visitors and residents in the islands as may have sociological interests.

Castes and Government. The most salient phenomenon in the social life of the Polynesians is the organization of society into rigid castes founded on the theory that the chiefs and aristocracy are descended from the gods. Pride in pedigrees is so universal among mankind that there is a strong likelihood that the sentiments associated with this aristocratic system are still in full rigor in parts of Oceania. Hence, a resolute effort should be made to collect as much relevant information as possible. A pitfall to be avoided is giving attention exclusively to the nobility: ethnologically the attitude maintained by the lower ranks toward their superiors is quite as interesting as the reverse and special attempts should be made to ascertain the precise facts in the case. Was the prevalent frame of mind one of cringing servility, or of rebellion, or of an overwhelming desire to extricate oneself from the pariah's status wherever that was feasible? The answers will doubtless vary in different localities, but everywhere this somewhat elusive problem should be attacked by interviews with as many native informants as possible. Among the questions to be asked should be included queries as to the precise status of such honored professional men as tatooers, sorcerers, canoe builders, house builders. Did their occupation bestow a definite rank? If so, how were they graded?

The matter of government, while intimately related with that of the caste system, must not be confounded with it. The example of Samoa shows that a very high social regard for the chiefs may go hand in hand with the chief's practical impotence when opposed by his council of landed gentlemen. The theory has been advanced that such a condition was secondary to an earlier stage in which the divine chief wielded practically despotic powers. Any concrete data suggesting that the historical development in a particular group is corroborative of this scheme, would be highly welcome.

Sexual Division of Labor. In every case the investigator should determine the precise division of labor between the sexes. Where the men are found as cooks, does this mean that they cook for the women or merely for themselves? Are women permitted to practise medicine or sorcery? What relative part did the men and women take in the cultivation of the soil? This question is one of great theoretical importance.

Segregation of Bachelors and Sexes. It is important to note whether the unmarried of either sex were segregated either in their sleeping-place or in their social life generally or both. This segregation may be limited to a separate allotment of space in the common dwelling, such as has been reported from Tahiti; or it may involve occupation of a separate bachelors' dormitory. In the latter case the other functions of this structure should be investigated. Did it serve as a lounging place for the married as well as single men during the daytime? Was it a guest house for strangers? What, if any, religious associations existed? Were wom-

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en rigidly excluded at all times, or on special occasions? In general, inquiries should be made as to the social intercourse of the sexes. Did men and women, e.g., eat together and dance together or separately? Were there any buildings beside the possible bachelors' hall, or men's clubhouse, from which women were barred?

Position of Women. This topic is partly merged in the two preceding ones. In addition all taboos affecting the female sex must be ascertained. Were women, e.g., not permitted to use canoes, as reported by Melville for the Marquesans? Were certain kinds of food tabooed to them? Did women participate in the tribal council? Could they inherit the chieftaincy and exercise property rights? Were they as free as men to take the initiative in divorce? Did they occupy a special hut or compartment during menstruation and confinement?

Sexual Life and Marriage. An important point to remember is again that the usage of lower and higher castes may have varied and that the customs of the commoners are scientifically quite as important as those in vogue among the blue-bloods. Hence a variety of informants should be used, including if possible several representatives of each social class.

To what extent was there looseness before matrimony? Was it limited to the lower caste? Did the young men have access to the spinsters' dormitory? Were there men who dressed and acted as women, as has been reported from Tahiti? Were these invested with a sacred character as in the Malay Archipelago and sometimes among the North American Indians?

Were there childhood betrothals? Were women permitted to propose? Whose consent was necessary to a union? Was there a real or pretended capture of the bride? Were gifts to the parents obligatory? Was there a dowry? Was a religious ceremony desirable or requisite?

Was there any preferential mating between individuals of fixed relationship? Did a man regularly prefer marrying a cousin? If so, define the exact relationship (e.g., mother's brother's daughter). Was the levirate in vogue, i. e., did a man inherit a brother's widow? If so, was he limited to an elder brother's widow? Was the sororate practised, i. e., did a man frequently marry his deceased wife's sister or might he be married to two or more sisters simultaneously? Did a man acquire marital rights over his wife's brother's daughter?

To what extent was there polygamy? Was it limited to the aristocracy? Was the first wife necessarily the principal one? Was there polyandry such as has been reported from Nukuhiva? Was there a limited group of men and women within which all males exercised marital rights over all females? For example, did this hold for a group composed of a man and his brothers on the one hand and a woman and her sisters on the other? Or did comrades share or exchange wives? Did the chief exercise marital rights over the women of his subjects?

What was the cause for divorce? Which parent was followed by the children? What was the punishment for adultery?

Rule of Descent. Though sibs (clans of British anthropologists) are generally lacking in Polynesia, they occur in Easter Island and their presence should be inquired into in the investigation of the less known groups. Although even in Easter Island they are not exogamous, the investigator should be on the lookout for evidence suggesting former exogamy.

Apart from a sib system, a definite rule of descent may hold as to the decent of property (for which, see below) and of rank. Is rank primarily inherited through the father or the mother?

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Children. Was infanticide practised? If so, was it limited to females? Was it practiced only or mainly by special classes of society, such as the nobility or a secret organization?

At what period did the child receive a name, and on what principle? How was its education conducted? Were there special schools, ecclesiastic or secular, as in New Zealand? How was instruction given in the different arts of tattooing, canoe building, and house building?

What customs were observed at or about puberty in the case of both sexes? Was tattooing or circumcision regarded as a necessary preliminary to marriage?

Property. Two topics should be investigated with special care,—the kinds of property and the rules for their transmission. More particularly, were there forms of incorporeal property, e. g., were certain privileges such as that of reciting a poem or chant more or less copyrighted? It is not at all necessary that the same rules of inheritance should hold for all kinds of property; hence, special queries should be made for each kind. To what extent property was held by individuals, by the community—or by minor groups, is an important problem.

As regards land, the same area may be held by different people for distinct purposes, as in New Zealand; one man may have the right to its vegetable produce, another the prerogative of hunting on it, etc. The best way to examine the subject is to proceed as concretely as possible: to take definite plots of land and to study their individual history with all the rights connected with it and their precise mode of transmission. This will involve a close study of the subject of kinship.

Kinship. By obtaining in each community studied a series of genealogies the field-worker should ascertain as accurately as possible the use of the existing kinship terminology. Where complete genealogies are not available, pedigrees of limited scope may prove useful and are always preferable to direct questioning. That is to say, except, perhaps, for the very simplest terms such as father and mother, the field-worker should avoid asking how such and such an English term is rendered in Polynesian. Taking for his basis the pedigrees previously recorded, he should ask: "How do you address John?" The genealogy will show that John is the informant's father's brother, and the answer can then be checked by asking other informants to designate corresponding kinsmen.

In connection with the kinship terms must be investigated the kinship usages, i.e., the special forms of social intercourse laid down for certain relatives by blood or connections by marriage. For example is a man's future spouse selected by his father's sister? Is a girl's mother's brother entitled to a share of the bride-price? Is a man entitled to claim part or all of his maternal uncle's legacy? May he marry his maternal uncle's widow? May he play tricks on his maternal uncle? May the children of a man jest freely—and even obscenely—with the children of his sister, and vice versa?

On the other hand, are there taboos regulating conduct, e.g., is a man forbidden to hold conversation with his mother-in-law or utter her name? Is an adult brother forbidden to chat with his adult sister? Is a man forbidden to speak with his daughter-in-law?

Attention should be paid to the correlation of certain of these usages with certain others. For example, may a person jest with those individuals of opposite sex whom he may marry? Must he refrain from speaking to those he may not marry?

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D. LANGUAGE

Four facts stand out in regard to Polynesian philology:

(1) The speech of the entire region consists of a group of essentially similar and closely related dialects.

(2) There exist printed grammars, dictionaries, vocabularies, or texts for nearly every part of Polynesia.

(3) Scarcely without exception natives, or many of them, are able to write their dialects correctly, besides sometimes furnishing translations into European languages.

(4) The Polynesian dialects are only part of a much larger family, the Malayo-Polynesian or Australasian, which includes all the languages of the Pacific (excepting those of New Guinea) and perhaps extends into the mainland of Asia.

From these considerations it follows that Polynesian philology has passed through the explanatory or descriptive phase, at least in the main. What is needed is coordinating synthetic work. This means a reconstruction of the genuine or original Polynesian tongue; the determination of its place in the larger Malayo-Melanesian-Polynesian family; the nature of the changes which the various branches of this ancient family have undergone in the course of a thousand years; the causes of these changes; and the continental families with which this Oceanic cluster of languages was connected in the dim past. These are problems which can positively be solved if they are attacked deliberately. But they can be solved only by a philologist acquainted with philological methods and endowed with capacity to use these methods in more than a mere routine manner. The right man, assured of the opportunity to devote himself uninterruptedly to the task from five to ten years, could solve the above problems in great part. Though he might not be able to answer all questions, he would, at any rate develop them to a point from which other competent students could carry on the research where he left off, and leave Oceanic philology as an organized, usable body of knowledge, where now it is but a mass of data. The method being a historic one, it can be predicted without hesitation that the findings would much transcend the linguistic field and would be hailed by students of race and culture origin as indispensable contributions to their problem.

More than one man would not be necessary, in fact not desirable; but this man must be thoroughly competent. Opportunity for field investigations should be provided when needed, but would be only a secondary consideration. It probably would develop now and then that some group—say the Paumotus—was insufficiently represented in the available data. In such case it should be possible to arrange for the prompt collection on the spot of the data needed to fill such a gap in comparative knowledge. This could often be done by engaging natives to write out what was wanted. But a linguistic survey of the entire Polynesian area *de novo,* when there already exists a wealth of data scientifically undigested, would be an unwise expenditure of time and money. This available literature, so far as it is worth while or necessary, should be mastered and made the basis for a synthetic study of the whole group and beyond. Of course the linguist may and is likely to want to make a fairly rapid field reconnaissance himself, so as to get a sound phonetic basis and find himself in a position to interpret the published data rightly. Experience in such matters has shown that an overhauling at first hand of work done by others is apt to be unexpectedly profitable. There is, after all, no substitute for direct impressions in linguistics. It is like art. In both fields one may talk a deal around the subject and,

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failing direct contact with the source, go far afield. However, such rapid field reconnaissance would not entail very intensive work at many points. It would give point of view, perspective, and vantage point from which to evaluate what is already more or less adequately recorded.

Again, it should be noted that the linguistic problem of Polynesia is an integral part of the larger question of Malayo-Polynesian and the still larger Australasian group. It is greatly to be desired that the investigators have that complete grasp of linguistics essential to a perspective treatment of the languages in and about the Pacific.

Inasmuch as the work should be in the hands of a philological specialist, there would be nothing gained by setting the members of ethnological exploring parties, who would ordinarily be without specific philological training, to the task of compiling grammars and vocabularies. Their work and linguistic research should be divorced as far as possible. It is true that an ethnological explorer needs a working knowledge—a *speaking* knowledge—of the dialect of his area if he is to do his ethnology in the best possible way; but it should be clearly understood that what is a temporary *tool* to him is an *end* to the philologist and that the latter cannot depend on the by-products of ethnological investigations. Only by separating the two sciences of ethnology and philology can each be specialized to the degree of exactness necessary to new valid conclusions.

E. MUSIC

Collections of songs, chants, etc., can usually be made with little expenditure of time or money. The chief expense is the slight cost of phonograph cylinders. The securing of several hundred records from each group would assemble a notable and unique collection of Polynesian native music in a few years, at a total cost of probably not exceeding one thousand dollars. This would make possible at any future time an exhaustive comparative and analytic description of Polynesian music by a trained specialist.

The technique of phonograph recording is simple and readily acquired after a few trial records are made. A few hints follow:

(1) Part or choral singing should not be wholly neglected in favor of individual voice; although more difficult, fairly adequate records of several simultaneous singers can be obtained.

(2) Rhythmic accompaniments are often an integral part of songs. They are usually impossible to record with full intensity, but cover a point that is invaluable to the student of music.

(3) A fair proportion of the cylinders should be devoted to repetition of songs by (a) the original singer at another time, and (b) other singers. Primitive music, being noteless, is more fluid than ours, and for an accurate study the variations are as important as the basic themes. A hundred records bearing a hundred different songs are less valuable than fifty songs obtained once each, plus ten obtained twice from the same singer, plus ten obtained twice from a different singer, plus one obtained from ten singers.

(4) Identification numbers should be cut at once into the edge of wax cylinders instead of being written on the box.

F. HISTORICAL RESEARCH

In order to appreciate the cultural and ethnological characters which were the original possession of the Polynesian peoples, it is necessary to define, with as much accuracy as is possible today, those contacts which have been made with Polynesia by each voyager. It is not only desirable

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that we should know the exact cultural phase of the peoples of Polynesia before the advent of the British navigators of the later portion of the eighteenth century; but it is essential that we should be in a position to appreciate their condition before any contact had been made with the earlier Spanish and Dutch navigators and with the Pacific whaling fleets. In order to obtain this very necessary knowledge, a great deal of historical investigation must be made. A well-qualified student of history, equipped with a working knowledge of Latin, Spanish, and Dutch, could work with advantage in any of the large centers of learning where good library and research facilities are available. But such research should be supplemented by the examination of archives in Spain, Mexico, and Manila. An exhaustive study of the existing records of early Pacific voyages is a great desideratum at the present time: its findings would yield results of importance to botany and zoology as well as anthropology in its widest sense. It should therefore be undertaken with the definite aim of meeting the requirements of these different branches of science. In order to make the knowledge gleaned from such a research available to the student it is suggested that all references be prepared in such a way as to make possible their incorporation in a card-index system.

Manuscript material in general could doubtless be enriched by collections of letters and papers from early missionaries and travelers. Possibly the files of the Linnaean Society and similar organizations contain papers of importance, but a field of special promise lies in the records of courts where native custom must have received consideration.

2. Anthropometric and Anatomical Research

The Polynesian problems under this head are of two sorts: local and general.

Local Problems. As an illustration of local problems we may use the Hawaiian islands, for with various modifications due to the size of the population and the number of racial types involved the same problems are found elsewhere in Polynesia.

(1) The first local problem is the accurate definition and description of the Hawaiian type or types. This involves the study of living natives and a representative collection of skeletal material systematically collected. Such a study should result in conclusions as to the racial affinities of the Hawaiians, point out their specializations or local characteristics and indicate their homogeneity or heterogeneity.

(2) A second local problem is the modern intermixture of racial types. For this problem the Hawaiian Islands are an ideal laboratory. Beside yielding general information on the laws of heredity, such studies should give answer to such practical questions as to what races produce the most homogeneous crosses and what effect such intermixture has on the human groups. Are the results desirable or undesirable mentally, morally, and physically? Are the half-bloods more or less fertile than the pure race?

(3) A third and very important local problem is the question of growth. The schools of Honolulu offer the opportunity of studying, side by side, large groups of Hawaiian, Japanese, Chinese, and Portuguese children, and various types of crosses all growing under the same environmental conditions and as nearly as possible of about the same social and economic status. The conditions for this experiment are as nearly ideal as we may hope to find anywhere. Such a study should include medical and dental investigations and promises to be of direct economic interest to the Territory.

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(4) Closely related to the question of growth is one more purely environmental. In the Hawaiian Islands we have an opportunity for studying Japanese born in Hawaii and Japanese born in Japan, Chinese born in Hawaii and Chinese born in China. We have an excellent opportunity for testing the stability of these types under different environmental conditions.

The four problems outlined above are, in our opinion, the most important local researches demanding immediate attention in the Hawaiian Islands. Any one of them involves serious research on the part of one or two men for at least a year. With some modifications the same problems exist in other Polynesian Islands. For example, in Samoa and Tonga we encounter Melanesian intermixture in place of Chinese. Thus the same general recommendations will apply to all.

General Problems. Problems concerning the racial affinities of the Polynesians, their inter-relationships and the probable extent of their physical contact with other races in the course of their migrations, belong to a different category. The satisfactory solution of these questions, in a reasonable length of time and with a reasonable outlay of money would necessitate the investigation being undertaken by one man or at most two or three men working in the closest coöperation. We think it is fairly obvious that these men should be trained and interested primarily in physical anthropology. While in a short space of time it is possible to train an ethnologist or archaeologist to fill out set forms of anthropometric records, it *is* impossible in a week, month, or even a year to equip him to carry on intelligent research in physical anthropology. A blank covering all the essential points would be too cumbersome and staggering to yield desirable results. This statement should not be taken as questioning the ability of ethnologists or archaeologists to do scientific work, for we believe that physical anthropologists are equally unfitted to do ethnological or archaeological research. We make no specific recommendations as to technique because it is taken for granted that the men selected to carry on these specific researches will be properly equipped.

Further, the prosecution of the physical problem in Polynesia is of such nature that it is desirable to separate it entirely from other phases of anthropological research. The general plan of procedure should be to provide for a year's study in one of the larger and preferably outlying groups for purposes of orientation and foundation. After a fairly thorough study of one group on which to build, he could proceed rapidly with other selected islands and determine the modifications encountered. The logical starting point would be any one of the areas which we believe to be most distant from the point of dispersal and which presumably contain end types. Under this head come the Hawaiian Islands, the Marquesas, Paumotu, and New Zealand. From these marginal areas the studies should be continued in the Society Group, Samoa, Tonga, and Fiji. Our knowledge of the Polynesians will be incomplete until at least one Melanesian group, preferably the Fijian, has been studied. For a complete rounding up of the problem either the Marshall or Gilbert groups should be visited. If it should not be possible to carry out this program in full, the most profitable procedure would be to confine the study to one marginal group and proceed to the assumed points of dispersal, Tahiti, Samoa, Tonga, and, if necessary, Fiji. The scheme can be expanded or contracted to meet the requirements of time and expense.

Collection of Data. As the Polynesians are on the road to extinction and assimilation, the collection of photographs, plaster casts, skeletal materials, etc., is of the greatest importance. While such collection is best done by a specialist in physical anthropology, it may be profitably supplemented

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by field-workers in other lines. This is particularly true of plaster casts, which may be successfully taken after a brief period of training.

3. ARCHAEOLOGICAL RESEARCH

In the insular areas of the Pacific, the fundamental problems are the origins, migrations, and external contacts of the inhabitants. Our chief interest in this connection centers in Polynesia. Since the Polynesian race is still represented in the flesh and shows, through its traditions, continuity from the present to the time of its residence outside the Pacific, it is difficult to consider the problem from an archaeological standpoint alone. Kitchen middens and other features suggest earlier habitation in the Pacific, but as the case stands today there are no good grounds for presupposing the presence of a race prior to the Polynesians. It follows then that while archaeological work must necessarily be limited to the specially versed in the field technique of the subject, Polynesian archaeology requires a comprehensive knowledge of Polynesian culture. As stated under an earlier section of this report, we recommend that material culture and archaeology be placed in the hands of a single investigator. Further, since in a number of the Islands the most important remains are of structures for religious purposes, the archaeologist must at least work in close coöperation with the students of culture. We commend the present plan of the Bishop Museum, Honolulu, to send two men to each group, one to investigate material culture and archaeology, the other to give his attention to religion, mythology, social organization, etc., thus recognizing the complementary relation between ethnology and archaeology in Polynesia.

Since Polynesian archaeology is in most respects a virgin field, the first problem is to make island surveys. So far as our ethnological data go, the rule in Polynesia was for each island to be a political unit, governed by a chief or group of chiefs as the case might be. The exercise of absolute authority by these primitive monarchs enabled the undertaking of public works upon a relatively large scale and the development of insular individualities. Hence, both from cultural and geographic standpoints island unit surveys are to be recommended.

The order of proceedure on a particular island might be as follows: Location and plotting of village sites, and in relation to these, the water supply, cultivated fields, irrigation ditches, temple sites, fish ponds and weirs, all other evidences of native industries, and burial sites. As a rule Polynesian temple sites require careful plotting in detail to reveal possible differences in type.

Such a survey should not only reveal the content of the archaeology for the island examined but should give hints of time relations and local variations. Typical sites should then be chosen for careful study, with excavations where needed.

The investigator should bear in mind that the fundamental objective of this research is chronology, or relative time-relations. Having differentiated types of temple ruins, for example, he should then seek for evidences of difference in age. Superposition being the ultimate proof of time-sequence, careful search for such should be made. This applies particularly to shell-heap investigations where sections should be carefully taken, recording the depth and position of the various objects found. Since the fauna must also be worked out with great care, it is advisable to take up these sections in layers along arbitrary levels and all of the shells and bones worked over with great care. This will require ultimately the service of several specialists, but until typical deposits have been treated in this way no great confidence can be placed in the result.

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To these general recommendations we add the following comments:

Structural Remains. The mecca of Polynesian archaeologists is Easter Island, which has been known to Europeans for two hundred years, but seldom visited. The problems here are the gigantic stone images, stone sculptures, and stone platforms. In the last decade, several expeditions have visited this spot, and the partial reports received indicate that the stone work pertains to the ancestors of the present people, generally recognized as Polynesians. Yet, until final reports are received, it would be well to postpone any recommendations in regard to Easter Island.

Remains of Polynesian villages, temple sites, forts, graves, fish ponds and weirs, and water courses are reported in the following islands still inhabited by Polynesians: The Hawaiian, Marquesas, Gambier, Society, Austral, Cook, Tonga, and New Zealand, to mention the principal groups—in general the high or volcanic islands, or those of greater size, where the country furnished the wherewithal to build. With the onrush of civilization, such remains as are not entirely destroyed are rapidly disappearing, and only prompt work can save for posterity the data which are sought.

In Hawaii, most of the temple sites have been located and described. In the Marquesas little has been done. In Tahiti and the neighboring groups we have descriptions and illustrations of the more important archaeological remains from the accounts of the early voyages and missionaries. In Tonga we have accounts by Mariner of certain features which give an understanding of the remains now found. In New Zealand, much work has been done but since intensive search frequently reveals what is not at first apparent, the New Zealand field invites further research. In connection with the temples or other forms of worship there were stone images not as large as those in Easter Island, which have been reported as remaining in the Marquesas and Austral Islands. The fullest inquiries should be made about these without delay.

There is a famous trilithon at Haamonga in the Tongan group, and while formerly supposed to have been prehistoric, it has latterly been shown, through traditions, to have been of Samoan origin. However, the like has not been found in Samoa, so that the matter remains to be settled by further investigation.

Shell-heaps and Middens. Kitchen middens have been referred to and are frequently associated with rock-shelters. Both have been found and worked in New Zealand. They belong to temperate climates, where food would be gathered in quantity and taken to a shelter for eating. In tropical sections, where the balance of the Polynesians are to be found, conditions were different. There was no urgent need for shelter, and much of the molluscan food was eaten where gathered. On this account, we should expect few kitchen middens in the tropics. In rare instances, caves and shelters have been used by Hawaiians for dwellings and workshops, and where found have furnished valuable material. They have only been revealed by detailed search; hence by the same method, they may be brought to light in the southern groups.

It is chiefly from such remains as these that we get the most definite data for the time sequences of culture. Owing to the fact that New Zealand seems to be the part of Polynesia where such remains abound, we must look to the archaeologists of that country for the last word upon the subject.

Burials. The Polynesian system of sepulture varied, bodies being placed both in caves and underground. No systematic work has been done in the way of collecting skeletal material in the Pacific; but as this material (the most valuable for the determination of the Polynesian area) deterior-

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ates with great rapidity in the countries of deposition, we would regard its collection as a matter of paramount importance.

Uninhabited Islands. There are many other islands regarded as having been inhabited by Polynesians which were found deserted at the time of their discovery by foreigners. We state they were inhabited by Polynesians, merely by inference, on account of their geographical relation to the inhabited islands. These islands contain much archaeological material, the real origin of which we do not know . Among them are Sala-y-gomez, Pitcairn, Oeno, Malden, Christmas, Fanning, Washington, and Necker Islands in Eastern Polynesia. In the west is the Kermadec group, and no doubt better acquaintance with the outlying islands would reveal others of similar interest. Archaeological research should be directed at once to certain of these islands which are now inhabited by workmen brought in for commercial purposes, before more damage is done by unscientific workers. These islands would be expected to furnish valuable evidence as wayports of the Polynesian migrants.

Preservation and Restoration. Archaeologists in this field should endeavor to create a public demand for the establishment of parks enclosing the most important remains. The Territorial Government of Hawaii has recently initiated such a policy and placed the examination and restoration of the remains under the direction of the Bishop Museum. We hope that the governments in control of the islands of the Pacific will take steps to preserve for scientific investigation all *large* structural remains within their respective provinces, and, in addition, one example of a village site in each island, if it can now be found. There is need for urgency in this recommendation, as has been shown in the Hawaiian Islands and as is further illustrated by the reported destruction of a very famous temple site in Tahiti. (This is the oblong stepped pyramid at Papara, illustrated and described by Cook and other voyagers and therefore made of world-wide interest.) Of equal importance is the need of governmental aid in securing skeletal material. We regard the New Zealand law restricting exportation of anthropological specimens as of benefit to science and hope to see its provisions extended throughout the island section covered in this report.

Archaeology in Other Areas. While this section of our report is limited to Polynesia, the recommendations we have made apply almost equally to Melanesia and Micronesia. The satisfactory interpretation of a chronology for Polynesia, for example, must await similar data for the adjacent islands. Micronesia promises to be of the greatest importance, for there we find conditions similar to those in Polynesia—monarchial governments powerful within their island spheres, and large structural remains. Two places may be mentioned in particular, the ruins of Metalinim at Ponape in the Caroline Islands and the stone avenues at Tinian of the Marianas, and there are others. These are prehistoric as far as the present Micronesian traditions are concerned and have partly developed on Ponape. They present no analogy to the work of Polynesians, though they have been suggested as the evidence of the routes of Polynesian migrations. There are also stone graves in this section reminiscent of those in Tonga, and they should be investigated for possible connections. The point is awaiting solution.

Fish ponds, or weirs, are present as in Polynesia. These structures extend throughout Polynesia, Micronesia, and Melanesia, the Philippines and the Malay Archipelago to the southeast, and southern portions of Asia. The exhaustive investigation of this culture trait is recommended.

4. PSYCHOLOGICAL RESEARCH

Research in race psychology is as difficult as it is important. There is scarcely a subject in regard to which dependable knowledge would be of

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such profound applicability in social, political, and economic relations. Yet actual scientific data of incontestable interpretations are scant; so scant in fact that the world at large scarcely realizes that the ignorance exists or that its dissipation would be of intensely practical value. One of the chief obstacles in the way of progress in understanding of the psychology of races has been the fact that any community or nationality is always the product of two sets of factors: (1) the inherent psychical endowment of the individuals composing the group; and (2) the culture or traditional accumulation of mental products characteristic of the group as a group. Psychological tests have been devised to ascertain with considerable accuracy the mental traits and capacity of separate individuals as compared with other individuals *within the same culture*. Used with individuals belonging to *different* cultures, the large majority of intelligence tests yield ambiguous results as it is extremely difficult to determine what in their findings should be referred to individual hereditary equipment and what to mass culture. Progress in this problem can therefore be achieved only through a technique which discriminates the individual psychologic and the group cultural elements in the living material investigated. This means, apparently that the beginnings must be made by a coöperation between experimental psychologists, who are experienced in dealing with the individual qua individual, and field-trained anthropologists, who through primary concern with social data as such have developed a "feel" and power of instinctive recognition of what is of cultural origin. The complete surmounting of the language barrier, important as this is, would be only a first step toward the accumulation of real data on comparative race psychology. Coöperation between the two sciences, in the form of jointly conducted investigations—not merely parallel or simultaneous but actually collaborative—thus seems called for.

As regards Polynesia, two openings present themselves for attack. The first would be an investigation, by a psychologist and ethnologist working hand in hand, of some of the least civilized and missionized native groups in the Pacific Islands. Except for the Torres Straits Expedition twenty years ago, when intelligence tests were still in their infancy, no serious attempt of this kind seems ever to have been made. The results of an expedition therefore promise to be rich if the work is entrusted to properly qualified men. It would be necessary that these men control not only their own techniques in most modern form, but that they possess an active understanding of the problem, versatility, and imagination.

A second line of attack would seem to be furnished by the present inhabitants of Hawaii, who are of notoriously diverse racial and cultural provenience but rapidly assimilating toward a uniform Caucasian mode of life. Their children especially must now be exposed to nearly uniform cultural influences, while six or eight racial types are represented in frequent racial purity—Polynesians, Mongolian, Chinese, Japanese, and Koreans, Malayan Filipinos, Caucasian Porto Ricans, and Portuguese, etc. Here, while conditions are "artificial" in the sense of being no longer national or aboriginal, the complications caused by the mingling of the indeterminates, culture and heredity, would be at a minimum, and less intricate checking would probably be required. Besides, abundant material could probably be made available through the school authorities.

In this discussion it has been assumed that the psychological research of greatest interest would be that relating to general intelligence. Certainly the present status of mental testing points to this line of attack as the most promising. In general, methods for the isolation and measurement of special abilities are still in a very backward state. It is probable, however, that something could be done in this field. In the schools of Hawaii, for exam-

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ple, measurements could be made which would gauge the relative sense with which native children master the different subjects of the school curriculum. In particular, mathematical and musical ability could perhaps be fairly accurately measured. In the case of mathematical ability comparisons would of course have to be limited rigidly to racial groups which had had equal opportunity and incentive for learning the subject. Music, on the other hand, offers a relatively simpler problem if, as Seashore's data seem to indicate, the elemental traits which underlie musical ability are practically non-improvable by training. Seashore's tests could probably be applied to the most primitive Polynesians, with only minor adaptations, and the results could not fail to be of great interest.

The measurement of racial differences in general intelligence is of course extremely difficult and will demand the most cautious and painstaking labor, but it would not seem to be impossible. The problem is primarily that of devising tests which would bring into play all the important intellectual processes but which would be relatively little influenced by differences of cultural status. In judging the validity of a mental test with reference to this point it is unnecessary to rely upon personal opinion, even of the most competent. Investigations have shown that within certain limits of error it is possible to determine the extent to which the results of a given intelligence test are subject to cultural influences. The method is to compare the results of a given test for two groups of individuals differing only in cultural status; one group primitive, the other considerably modified by alien culture. Tests which yield similar results for the two groups while at the same time bringing out the individual differences among the members of each group taken alone, must be regarded as valid.

Accordingly, the first step would be to make a selection of the existing tests which came nearest to meeting this criterion and to devise new ones which would seem to promise well in this regard. The second step would be to submit the entire collection of tests to trial in order to secure co-efficients of cultural influence. The least satisfactory tests could then be eliminated and the best retained and improved. These preliminary investigations for the purpose of preparing suitable psychological methods would require the full time for at least one year of a well-trained psychologist and an assistant aided by a committee of psychologists acting in an advisory capacity. While such preliminary investigation would entail a good deal of expense, it is absolutely necessary if worth-while work is to be done in the comparative study of racial intelligence. Attention is called to the fact that when satisfactory test methods have been perfected for the study of Polynesians they will probably be found to have wide applicability in the study of other races.

To indicate in detail the types of tests which would probably be found useful for the present purpose is outside the purpose of this statement. A few general principles, however, may be laid down.

In the first place, the methods should be prepared with a view to individual rather than group examining. While the method of individual examination would limit greatly the number of individuals for whom measurements could be secured, this would doubtless be more than compensated by the greater reliability of results. With proper attention to the errors of sampling, careful measurements of a few hundred individuals of each of the races to be compared would give a reasonably satisfactory basis for conclusions.

Secondly, the tests would have to be absolutely independent of the language factor. Psychological work in the army has demonstrated that this criterion can be met. It was met by several tests in the Beta scale and

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by a majority of the tests in the so-called "performance scale" which was used in the individual examination of illiterates and foreigners.

Independence of language, however, is not sufficient. It will also be necessary, in the third place, to avoid the use of tests making demands upon mental processes which the life experience of the individuals have not brought into play. This criterion is obviously harder to satisfy. It is not satisfied by a majority of the Beta tests, or in general by any test of the "pencil and paper" variety, even those which require merely the completion of pictures or forms, reproduction of drawings, and similar responses. A few of the ten tests in the individual "performance scale" are less objectionable in this respect, but it is probable that few if any existing tests can be taken over without greater or less modification of both content and proceedure. Caution will especially have to be exercised in the use of tests involving pictures, as pictorial representation is always highly conventionalized. The same holds for tests involving the use of mazes, geometrical forms, form boards, etc., though the problem here is not quite so serious. It would seem possible to devise performance tests of the following types which would be relatively free from the influence of training: a maze test, a memory span test, a substitution test, a form board test, a block design test,[1] and other tests of "combinative" ability (i. e., tests involving intellectual synthesis).

The most serious fault of most existing tests of the above types is that they do not make sufficient demands upon the higher mental processes, but this fault can doubtless be largely eliminated. The necessity of improving existing performance tests in this direction cannot be too strongly emphasized in the present connection, for all the available data indicate that the decisive intellectual differences between "superior" and "inferior" races, or between "bright" and "dull" individuals of the same race, concern chiefly the higher thought processes of abstraction, reasoning, and judgment; the synthetic abilities generally. It is these processes which have made civilization, as we know it, possible. While it may be desirable for the sake of completeness to include tests of motor coördination, reaction time, sensory acuity, perception, etc., we are not warranted in attaching anything like as much significance to differences on these lower levels as to those found on the higher levels. Indeed, large differences between races on these lower levels may be practically non-existent.

When suitable methods have been prepared they should be applied to three hundred or more "unselected" adult individuals of each of two or three primitive groups of Polynesians, and if possible to an equal number of each of several Hawaiian groups, including less primitive Polynesians, Chinese, Japanese, Malayan Filipinos, Portuguese, and Americans. Six or eight groups of three hundred individuals each would give a solid basis for comparison.

A year would probably be required for the preparation of methods, another year for administering the tests, and a third year for the working up of results. For the entire period a psychologist and from one to three assistants would be necessary.

In emphasizing the importance of research on racial differences in intelligence it is not implied that other lines of psychological research may not be desirable or feasible. The emphasis has been determined chiefly by the status of existing methods. Even if the main purpose of the research had to do with intelligence it could be expected that during the progress of the work systematic observations would be made on instinctive, emotional,

[1] On the order of one devised by S. C. Kohls of Stanford University, and described in a doctor's dissertation not yet published.

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and volitional responses and attitudes. It might even be possible to arrange a worth-while test for certain non-intellectual traits, taking as a point of departure such tests as that of Woodworth (for detecting psychopathic traits) that of Pressey (for measuring emotional reactions), and that of Voelker (for measuring reliability). The use of such tests with natives would of course have to be confined to those who had had educational opportunities similar to those enjoyed by children in the average city of the United States.

Psychoanalysis. Suggestive parallels between the mental products of civilized psychopathic or neurotic individuals and primitive social groups have been repeatedly pointed out in recent years. These analogies are no doubt important but can as yet be interpreted only speculatively because almost nothing is known of the manifestations of individual psychopathology in uncivilized life, and not much more of the forms taken by the subconscious of the normal uncivilized individual. Data on these matters would therefore be unusually valuable, and Polynesia probably offers at least as good a field for research as any other area. If the work is undertaken by psychiatrists or psychologists, they should be thoroughly familiar with the milieu; and reciprocally as regards abnormal psychology if the research is entrusted to anthropologists. A joint coöperative investigation would best meet the requirements of the problem.

III. SYNTHETIC RESEARCH.

Field-work in the Pacific Islands and elsewhere is largely concerned with the compilation of scientific data. The collection of such data for a single group of people is a task of such proportions that it will consume the greater part of a lifetime. Hence, the field-worker can be expected to do little more than faithfully report and systematize the data he has collected. It follows, then, that a comprehensive view of Polynesian culture and its relative position in the culture of man as a whole is a problem of much greater breadth than any of specific undertakings of the field-worker. We recommend, therefore, that as soon as practicable, provision be made for the support of two or more competent investigators able to give several consecutive years to the highest kind of synthetic research in this area. We recommend that at least three high-grade research fellowships be established, one for each of the following subjects: Polynesian linguistics, cultural history of the Polynesians, racial affinities of the Polynesians. In our opinion, the above order represents their relative urgency. It is a matter of common knowledge that linguistic research, when properly undertaken, throws more light upon the origins of cultures and peoples than any other single line of investigation. For specific recommendations on this subject, see the section on Language.

It is our opinion that the establishment of such research fellowships under the auspices of research institutions in and around the Pacific would lead to results of the highest importance.

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HAWAIIAN FLORA AND FAUNA

SALIENT FEATURES OF HAWAIIAN BOTANY

By Charles N. Forbes

(Unrevised manuscript.[1])

Botanical research in Hawaii has been mainly confined to the collecting and naming of plants, and to general accounts of the flora, but no results of careful ecological work have yet been published. Since the publication of Hillebrand's comprehensive flora in 1888, several large collections of Hawaiian plants have been made and as a consequence the distribution of most of the endemic genera, and many of the species have been considerably extended. Many new species and a few genera have been added to the flora, partly on account of more modern views concerning species, but chiefly because collecting has been greatly facilitated by numerous trails made by water surveyors and others through sections which were inaccessible and unknown to Hillebrand and the early collectors. While a great amount of systematic work has been done in recent years, local workers are placed at a certain disadvantage in being so far away from the larger herbaria where the types of early described Hawaiian plants are kept, and which it is more or less necessary to consult before serious work can be undertaken in naming plants with which we are familiar through field experience. There are large collections of plants in the herbariums of the Bishop Museum and the College of Hawaii, but on account of local difficulties in collecting and the nature of the flora itself the collections can never be complete until every single ridge and gully of the whole island group has been visited in at least two different seasons. A large number of the most interesting plants have a discontinuous distribution, occurring as small clumps or even single individuals separated from each other by miles of forest which is often of the same character, some of these species even extending to more than one island. Recent monographs give a true indication of the revision necessary in systematic work with the flowering plants of Hawaii. Hawaiian ferns are perhaps the best known group, and it is

[1] The death of Mr. Forbes occurred August 10, 1920, during the session of the Conference.

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doubtful if there are many unnamed species, but interesting problems of relationships will have to be worked out especially in the genus Asplenium in which the local species seem to form closely related groups, although many of the species also found outside of Hawaii come from widely separated localities. The lowly hepatics and mosses of Hawaii have proven to be of great interest to students of plant distribution, and while fairly well known systematically our knowledge of them is by no means complete. The algae are fairly well known; systematic work on the lichens is practically complete; but of the fungi we know almost nothing. The higher forms of fungi, for some unknown reason are extremely rare in Hawaii, although in Samoa and other islands of the Pacific where the conditions are apparently the sáme they are abundant. Our knowledge of the Mycetozoa is limited to six species none of which are limited to Hawaii, but others will undoubtedly be found when more local workers become interested in this group. Summarizing our knowledge of the systematic botany of Hawaii I would say that *all* the genera, *most* of the rarer species, and *all* of the common species are fairly well known and are represented by specimens in the local herbaria, but that our knowledge of the range of the species, and the limits of variation even of the commoner species is very incomplete, and will require further study and collecting.

The most important factors in the local distribution of Hawaiian plants are due to volcanic eruptions. All the surface of these islands with the exception of a narrow fringe of coral rocks near the shore is of volcanic origin. The topography both of the recent and heavily eroded mountains is different from that where most ecological work is being carried on at the present time. The igneous rocks and the resulting soils are different from those in most parts of America. The physical differences of rocks are obvious, but we know little of the chemical differences, and nothing at all in so far as their influence on the indigenous vegetation is concerned. Plant invasion on new volcanic areas has occurred countless thousands of times throughout the Pacific, and only after a thorough recognition of this process can a clear insight be obtained of Hawaiian vegetation. Also the destruction of natural vegetation by volcanic eruptions has been a common occurrence, and I do not think we yet realize what a vast influence these forces

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have had on plant distribution throughout the Pacific. In any discussion concerning plant distribution we shoud not overlook the effect of violent eruptions in causing the migration of birds, and even the occasional dissemination of seeds to long distances. Last year a comparatively insignificant eruption from Mauna Loa caused the whole Hawaiian group to be enveloped in a blue haze for a distance of nearly 1000 miles, and to what extent this affected the weather and incidentally the season's growth for that year, for lack of sufficient data we can only surmise. Volcanic phenomena and their relation to either native vegetation or cultivated crops have received but scant attention, and all that has been written on this subject would hardly fill a moderate sized volume.

Most barren rock surfaces require ages of weathering before they will support the higher forms of plant life, but portions of the smooth pahoehoe lava flows on Mauna Loa, become vegetated with higher plants within two years, often within a year, after an eruption. Rough aa flows and cinder become covered with vegetation at a later date, The first conspicuous plants to appear on a new lava flow are a lichen, Stercocanlon, and a moss, Pilopogon, while at about the same time or soon after, certain ferns appear in the cracks of pahoehoe lava, especially a folded form of *Polypodium pellucidum*, a fern greatly resembling the widely distributed *Polypodium vulgare* but limited to Hawaii. When it occurs on open lava flows, the simple, once pinnate frond is folded together like a hinge, the pinnae at the same time being twisted upward so that the lower surface bearing the fruiting bodies points downward. Usually this fern occurs in the rain forests as an epiphyte, and the frond is flat like most ferns. Except when *Polypodium pellucidum* is replaced by *Nephrolepis exaltata* on the lower levels the next most common fern is one belonging to the genus Sadleria. There are six species of this genus in Hawaii, all but one of which are endemic, *Sadleria cyatheoides* only occurring elsewhere on the island of Sumatra. The first flowering plant to appear is a variety of the Ohia, *Metrosideros polymorpha*, which almost always starts as an epiphyte on the Polypodium or Sadleria. After these plants form a scattered association, other plants gradually invade the area, and in the course of time varying with the situation, different formations

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such as rain forests, dry land forests, and meadows, come into existence.

A new volcanic area in Hawaii may be called a semi-xerophitic habitat, even though the yearly rainfall may reach as high as 350 inches. The first plants to invade the new flows on Mauna Loa on Hawaii are invariably the same at all elevations, and on all sides of this mountain, in spite of the fact that the annual rainfall varies from 30 to 350 inches, and the greatest minimum temperatures from freezing point to 60 degrees. Evaporation experiments on the slope of Mauna Loa indicate that the evaporation rate on an aa flow is four times as great as in a rain forest. The open character of the habitat, the strong unobstructed winds, the black surface, strong reflected light, and quick run-off are the most obvious features affecting vegetation on a new lava flow. As the flow becomes covered with vegetation, these early characteristics gradually disappear, and the vegetation takes on the characters of that in the immediate vicinity, which is determined by the rainfall, elevation being an associated circumstance.

The zonal distribution of Hawaiian plant communities according to elevation has been described by a number of botanists, but no exact instrumental or careful ecologic work has yet been published, and the distribution of plants within the zones has not been carefully worked out. The lowland zone which is characterized by introduced plants has a rainfall varying from 10 to 60 inches. The lower and upper forest zones have a rainfall varying from 60 to 350 inches, and extend above the 5,000 foot level, the distinction between these two zones not being as definite as one might judge from the descriptions. The upland zone probably has a rainfall varying from 20 to 80 inches, and in its upper part, frost and even snow are not an uncommon occurrence.

The middle forest zones are of most interest to the visitor, both on account of the number of strange plants, and the unusual aspect of the forests. Practically all endemic Hawaiian plants are woody, and woody Lobeliaceae, Violaceae, Caryophyllaceae, Primulaceae, and Geraniaceae and Compositae, must always excite the wonder and interest of the plant lover, and incite inquiry as to their relationships with the herbs and woody plants of other lands. In Hawaii the botanical collector is always rewarded with a full load of flowering and fruiting specimens at

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any season of the year, and while there must be definite seasons for individual species they have not yet been carefully worked out. With a few notable exceptions the flowers are small and inconspicuous except when borne in large masses as is the case with the Ohia and the Koa, and they generally lack odor. Most rain forest plants start as epiphytes, and even on the edges of the forested areas one often finds common introduced weeds such as the sow-thistle, *Sonchus oleraceus,* and the sorrel, *Rumex acetosaefolia* growing as epiphytes. The original support of the larger forest trees, usually a tree fern, eventually dies, and the trees have great, irregular, stilt-like roots, or trunks, and in certain types of rain forest the explorer travels for considerable distances over great tangles of prostrate trunks and woody rhizomes, all of which are covered with epiphytic ferns, and great spongy balls of herpatics and moss. Climbing plants are represented by few species, the *Leie Freycinetia arborea* of the Pandanus or Screw-pine family being the most frequent. Endemic herbs with the exception of ferns are rare in the forests, and are mostly confined to the open bogs.

The most common endemic forest tree in Hawaii is the ohia, *Metrosideros polymorpha* and its varieties, which may be found in all habitats throughout the group. Pure stands of *Acacia koa* and Sophora of the Leguminoseae, *Osmanthus sandwicensis* of the Olive family, *Myoporum sandwicense* of the Bastard Sandalwood family, and *Dracaenia aurea* of the liliaceae occur, but most forests contain an unusually large mixture of many species, the principal families being the Rubiaceae or Coffee family, the Rutaceae or Orange family, the Araliaceae, Lobeliaceae, Gesneriaceae and Urticaceae or Nettle family. The Kukui, an Euphorbiaceous tree introduced by the Hawaiians some 1500 years ago, marks the limit of the lower rain forest, and its present distribution gives some indication of the amount of erosion which has taken place in the islands since that time, especially along the cliffs of the Waimea canyon on Kauai, and the windward sea cliffs of Molokai, where it now occurs in isolated hanging valleys. The other zones are of equal interest to the botanist and offer numerous ecological problems but are perhaps not as strikingly unusual as are the forested areas.

In concluding it is not out of place to draw attention to the rapid change which is taking place in the natural vegetation at the present time, not only because it is an interesting problem in

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itself but because of it, our chances for studying the primitive vegetation are rapidly decreasing. Beginning with the time when these islands first supported an enormous native population, the indigenous vegetation has undergone great changes, but it is only within comparatively recent years that wholesale destruction of the native flora has taken place. To cite only one example: on Haleakala, Maui, within the last 50 years dense forests have entirely disappeared from the whole south and east slopes of this mountain, while within 15 years nearly every large tree on the greater part of the north slope below 2,500 feet has died. This is usually due to a combination of causes, and the reason is not always the same in every case, but it is generally the indirect result of industrial and agricultural development. The introduction of domesticated and wild animals, the clearing of the land for wood or agricultural purposes, forest fires, ravages by insects, the competition of introduced plants, the building of trails, and the lowering of the water table as the result of water development have all played a part in changing the natural conditions of the endemic vegetation, which in the end must succumb to more vigorous plant species. In the course of time areas of a strictly indigenous vegetation will become smaller and smaller, and the chances for ecological work in virgin forests will have passed. The bulk of the present Hawaiian forests are of use only as conservers of the water supply, introduced trees being of much greater commercial value, and unless foresight is taken to preserve certain sections of the forest reserves for scientific purposes, it is only a question of time before there will be no more strictly virgin forest areas in Hawaii.

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ORIGIN OF THE HAWAIIAN FLORA

By Forest B. H. Brown

INTRODUCTION

The problem of the origin of the Hawaiian flora may be simplified by considering the seed plants apart from the spore plants and the dicotyledons apart from the monocotyledons.

The fact that spores can readily be transported long distances by any of the various agencies of dispersal (air currents, ocean currents, migratory birds) makes the problem of the origin of the spore plants difficult and uncertain of analysis. But seeds, with few possible exceptions, are ill adapted for transportation over great distances (2000 miles) by air currents, and there is little evidence that migratory birds have been materially more effective than winds in carrying seeds to land so isolated as the Hawaiian islands. The direction from which plant dispersal has evidently occurred does not correspond to any known path of bird migration if indeed birds had acquired migratory habits at the early period in which most of the plant immigrants appear to have arrived upon the islands. This, in connection with the fact that birds after long migration arrive with the digestive tract empty and presumably with the plumage and other parts of the body free from all but the most tenaciously clinging seeds, makes it improbable that either birds or winds have been effective to any appreciable degree in the transportation of seeds over great distances of sea; only the agency of ocean currents remains as a probable factor. The problem of dispersal is therefore simplified by restricting the discussion to the seed plants. Ocean currents may have operated directly in a few instances in bearing floating seeds or fruits such as the coconut to the islands; but in that the majority of seeds sink in water, it seems likely that as a rule they were brought in drift material.

The direction of flow of the Pacific currents of the present, however, is unfavorable for the transport of drift from the region (Central America) from which most of the plants appear to have come, and, further, would result in continuous rather than rhythmic dispersal. But there is reason to believe that at the time when dispersal occurred the currents of the Pacific were essentially different from those of the present. Plant evidence is in accord with this assumption as will be shown presently.

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COMPOSITION OF THE FLORA

It is a remarkable fact that nö gymnosperms have ever been found in Hawaii. Their absence, however, may be due solely to the fact that these plants have not succeeded in crossing the ocean, a supposition that is borne out by a number of evidences. For example, green cones sink in the sea water; the seed coats of most species are readily permeable to water; young seedlings are easily killed by adverse conditions of light and moisture. Moreover the high endemism of North American conifers in comparison to the Angiospermus makes it clear that these plants have shown little tendency to cross ocean barriers in any direction.

Gymnosperms being absent, the Hawaiian seed plants therefore comprise approximately one hundred and twenty monocotyledons and seven hundred and eighty dicotyledons, about nine hundred in all. The monocotyledons are in large part herbaceous plants not suitable for fossil preservations and are without the development of secondary wood which would make possible any systematic classification of anatomical character comparable to what has been accomplished in the dicotyledons. Furthermore, the grasses and many other monocotyledons have small seeds easily concealed in whatever the native might carry in long voyages from one island group to another and hence would be accidentally introduced. The monocotyledons, therefore, furnish meager and uncertain information bearing upon their geological history.

The Hawaiian dicotyledons, on the other hand, are largely (78 per cent) woody plants, especially the endemic species of the endemic genera of which 95 per cent are shrubby or arborescent; to this class belong nearly all of the trees of the indigenous forests. In this class of plants the various elements of the wood have attained a highly complex differentiation and clearly defined evolutionary tendencies are exhibited in each of the numerous specialized branches. Not infrequently the systematic position of a dicotyledonous species, genus, tribe, family, or order is morely clearly indicated in the anatomy of the woody stem than in the floral characters. Anatomy therefore serves to check the evidence or to bridge over gaps in the evidence based upon external characters. Furthermore, to the extent that anatomical details are preserved in fossil wood, such characters are of value in establishing the relation of existing floras to fossil floras.

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The dicotyledons, therefore, furnish evidence not only in the external morphology but in the anatomy of the stem and in the fossil record which bear upon their geological history, and the abundance of fossils of woody dicotyledons makes it possible to extend the investigation into the fossil record. The woody dicotyledonous plants therefore make favorable material with which to investigate the origin of the Hawaiian flora, and by confining the present discussion to these plants, many elements of uncertainty are excluded.

PROBABLE AGENCY OF PLANT DISPERSAL

The dicotyledonous flora as a whole numbers about seven hundred and eighty species but in all probability these have arisen from about one hundred and twenty-five ancestral immigrants. In the relationship which these descendants sustain to one another it is clear that these immigrants constitute a remarkably heterogeneous group, not less than seventy-four families being represented or an average of less than two immigrants per family. This is quite the contrary to what one finds in a flora resulting from an overland migration, but rather such as one would expect if brought from long distances as waifs and arriving one by one over considerable periods of time. There is nothing apparent in the flowers, fruits, seeds and other characters of these plants as a whole to indicate the operation of any selective agency of dispersal. On the contrary, the same high degree of heterogeneity prevails in the character of the fruits and seeds as in the relationship; the composition of the group appears to have been determined purely by the laws of chance and all evidences strongly favor the conclusion that plant immigrants must have been brought to the islands by some physical agency such as ocean currents. By any other agency many of the fruits or seeds would be impossible of transportation. Only a small portion, it is true, have buoyant seeds or fruits but there are none which could not have been brought by floating conifer logs or similar drift. And (1) with the predominance of conifers on the continent, culminating in the Triassic-Jurassic time (2) with the submergence of the region (Central America) from which the bulk of the Hawaiian flora appears to have originated and (3) with the changing of ocean currents when the Atlantic and Pacific were united through wide submerged areas of Central America, resulting probably in a more decided westward trend

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of the Pacific currents in the equatorial belt, it is clear that conditions in the past must have been more favorable than at present for the dispersal of American plants westward to the Pacific islands. And in that submergence of the Central American region has occurred rhythmically, it follows that the dispersal of American plants westward over the Pacific would occur at intervals, i. e. in dispersal waves; it is of great interest to find that the plant evidence bears out this supposition with particular clearness; not less than two dispersal periods (or waves of dispersal) may be recognized, or three waves inclusive of species introduced by human agency.

THREE WAVES OF DISPERSAL

So far as evidence goes there is little to indicate that the first plants to become established upon the islands arrived early in the history of the Angiosperms. Throughout the present flora, representatives of highly specialized families (metachlamydeae) such as the compositae, campanulaceae and labiatae make up a conspicuous element and are particularly characteristic of the group of plants which appears to have been the first to arrive. Nevertheless, it is not unlikely that the first arrivals antedate the first known fossil Angiosperms inasmuch as the fossil history of these plants does not begin until the dicotyledonous families are well differentiated.

That the periods during which immigration occurred were of long duration is shown by the great differences of age apparent in the several descendant lives. Also, there is a break in the floral composition and in the degree of endemism and other characters indicative of age, which separates the flora into distinct groups, or sub-floras, and makes it clear that immigration has not been continuous but has been interrupted at intervals. At least two periods or waves of immigration can be distinguished, or three, inclusive of the group of plants introduced by man, as follows:

1. The group of plants arising from the first period of dispersal is characterized by the large number of Compositae, Campanulaceae, Labiatae, Rubiaceae and Rutaceae which it contains. Affinities are largely with plants of Isthmian America, and all appear to have originated directly or indirectly from this region. Many of the tribes to which the Hawaiian island representatves belong. are, except for the Hawaiian representatives endemic to

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America, but the endemic units belong to a tribe (Prasioideae) distributed from southeastern Asia westward through the Mediterranean region, its only extra-continental extension in the Hawaiian islands. But the Hawaiian genera are most closely related to a genus confined to the west Mediterranean region and extending into the Canary islands. As will be shown presently, geological conditions existing in early Cretaceous time or earlier would have favored dispersal from this region to the Hawaiian islands by way of Central America. The following table is instructive:

PLANTS OF THE FIRST WAVE OF DISPERSAL

Family	No. of ancestral immigrants	Probable origin	No. of descendants
1. Urticaceae	2	American	3
2. Amarantaceae	2	"	5
3. Caryophyllaceae	1	"	18
4. Saxifragaceae	1	"	2
5. Rutaceae	2	"	28
6. Malvaceae	1	"	5
7. Violaceae	1	"	3
8. Begoniaceae	1	"	1
9. Araliaceae	2	"	18
10. Loganiaceae	1	"	9
11. Apocynaceae	1	"	1
12. Labiatae	1	Indirectly American	36
13. Solanaceae	1	American	4
14. Rubiaceae	4	"	40
15. Campanulaceae	3	"	93
16. Compositae	7	"	56
Total, 16 families	31 immigrants		descendants 322

2. The group originating from the second dispersal wave is next in age and is evidently of considerably more recent origin than the first. Evolution has in no case progressed as far as the creation either of endemic genera or of endemic sub-tribes, and not more than three species, on an average, have arisen from a single ancestral immigrant. In many cases the closest existing relatives occur in the region of the East Indies or Australia, but such affinities appear to be of a collateral character and remote from the center of origin. The second wave, like the first, seems to have come, in large part at least, by way of the Central American region, and during about Lower Eocene time. It is a remarkable fact that the ten largest families found in the Lower Eocene flora of the lower Mississippi valley (Lauraceae, Caesepiniaceae, Urticaceae, Papilionaceae,) Rhamnaceae, Sapindaceae, Myrtaceae, Mimosaceae, Anacordaceae,) are all abundantly rep-

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resented in that portion of the existing Hawaiian flora which has apparently originated from the second dispersal wave. It is of great significance, in this connection, that a cusp-pointed phyllode of the same size and obovate outline as the Hawaiian *Acacia koa* var. *lanaiensis* has been found in the American Lower Eocene. Even the uninervate character of the fossil is indicated in the phyllodes of young seedlings and juvenile foliage of the Hawaiian representative; not only the ancestral stock of the Hawaiian phyllodinous acacias appear to have come in this period from the American continent but inasmuch as a fossil stem with coco-like structure has been found among the fossil plants of the Canal Zone, it is probable that the coconut arrived in this wave of dispersal of American plants. This portion of the Hawaiian flora may properly be regarded as a relic of the American Lower Eocene. The first wave of migration must therefore greatly antedate this time.

3. A number of plants (breadfruit, candle nut and others) have, in all probability been introduced by primitive man. For sake of comparison these plants may be considered as a third group.

The plants originating from the first dispersal wave are almost exclusively confined to the interior uplands of the islands, occurring mainly at high elevations in the mountains. This is a characteristic feature of the group as a whole and is reasonably explained on the supposition that the ancestral immigrants were also interior upland plants, the continental angiosperms not yet having invaded the lowland or littoral regions where conditions were favorable for fossil preservation. If so, the tendency which plants of the first dispersal wave exhibit to inhabit the interior uplands is a relic character of the ancient angiosperms and antedates the fossil record.

Age is also indicated by the amount of evolution which has taken place on the islands. The existing representatives of the first immigration number between three hundred twenty-two and three hundred fifty species, but these appear to have arisen from thirty-one ancestral immigrants. All of the genera are endemic, and certain of these endemic genera constitute a closely connected series similar to those of a sub-tribe. In other words, not only endemic genera but endemic sub-tribes have been evolved on the islands, starting in each case from a single ancestral immigrant. The sub-tribes particularly are indicative

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of age and number six or seven as follows: (1) Schiedea-Alisinidendrion in the Caryophyllaceae; (2) triplasandra-tetraplasandra-Pterotropia-Reynoldsia in the Ciraliaceae; (3) Stenogyne-Haplostachys-Phyllostegia in the Labiatae; (4) Clermontia-Rollandia-Delissea-Cyanea in the Campanulaceae; (5) Cirgyroxiphium-Wilkesia and (6) Dubantia-Raillardia in the Compositae; and possibly (7) Hibiscadelphus-Kokia in the Malvaceae.

As an index of age, the extremely low generic coefficient of the endemic genera is particularly significant. On a mountainous topography, such as that of the Hawaiian islands the number of plant species is large in proportion to the number of genera. On more level topography, on the other hand, such as characterizes a large part of the continental areas, the number of species per genera is relatively small. On the Hawaiian islands there have been evolved genera with lower generic coefficient ($\frac{\text{genera}}{\text{species}} \times 100$) than their continental relatives, and in so far as change has probably taken place by slow degrees, it follows that, as long as change takes place, the coefficients of floral groups upon the same topography should vary inversely, though not in proportion, with the age of the group. Accordingly, it is quite as one would expect to find that the sub-flora originating from the first dispersal wave should have the lowest generic coefficient (13) and the sub-floras arising from progressively younger waves of dispersal should have progressively larger generic coefficients. The coefficients of the sub-floras originating from the first (oldest), second, and third (youngest) waves are respectively 13, 36, 47. (See fig. 1.)

The relative age of the three dispersal waves is also indicated in the anatomy of the wood. In dicotyledons of the first dispersal, the vessels of the wood have an average diameter of .12 mm.; dicotyledons belonging to the second wave, on the other hand have vessels of .14 mm. in diameter; those of the third wave (the introduced plants) have vessels of .22 mm. in diameter; or, arranged in sequence according to time, the diameters are .12 mm.; 14 mm.; 22 mm.; respectively. Plants which have been longest on the islands have (without exception so far as I am aware) vessels of extraordinarily small calibre, in several species being no larger than the fibres and almost indistinguishable from them, in cross-section.

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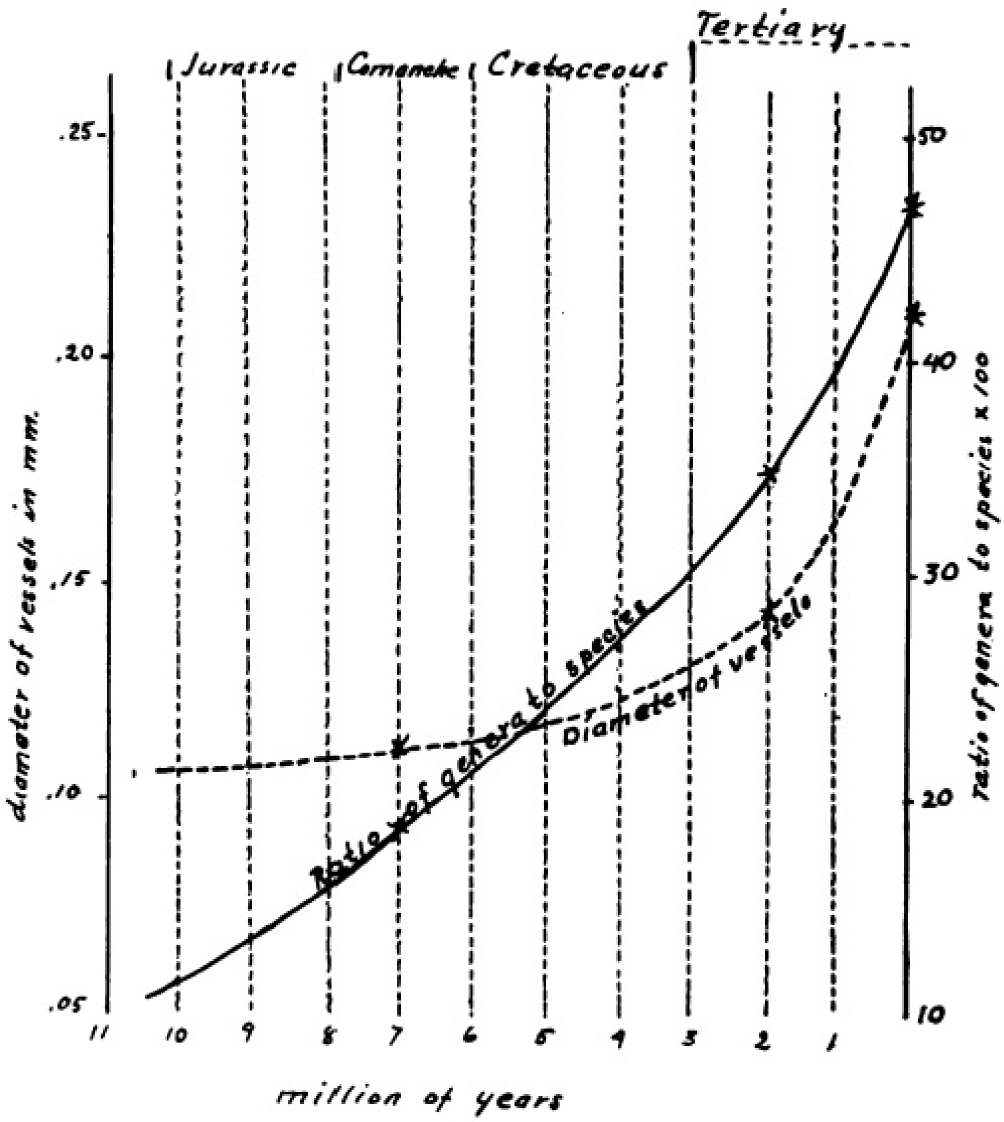


FIGURE 1. Curves showing progressive decrease of vessel diameter and generic coefficient with age in Hawaiian woody plants.

Reduction in size of vessels seems to have been an evolutionary tendency common to each of the descendant series arising from continental immigrants with vessels probably of relatively large calibre; and in so far as change has taken place gradually it serves as an index of age. Upon the supposition that reduction in size of vessels has been an evolutionary tendency many peculiarities in the Hawaiian flora are reasonably explained: (1) certain specialized endemics such as *Acacia koaia* have smaller vessels than their more generalized close relatives (*Acacia koa*); (2) large vessels are characteristic of

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continental fossil floras from which the Hawaiian representatives appear to have been derived; (3) peculiarities of the Hawaiian climate (low light intensity), uniform moderate temperature, high relative humidity) favor slow transpiration probably with the consequent reduction in the caliber of the vessels; (4) the average diameter of vessels in Hawaiian plants varies so long as change occurs, inversely though not in proportion, to the age of the flora; introduced continental species and continental island species like the breadfruit (native of Java) have vessels of far greater diameter than those of the endemics.

Hence Hawaiian dicotyledons have (1) smaller vessels and (2) a lower generic coefficient than their continental relatives and both of these characters appear, within limits, to vary inversely with the age of the flora. When the values obtained are plotted in relation to their chronological abscissae (fig. 1) curves are obtained in each case, and these curves are in essential agreement, the lowest values being characteristic of the oldest plants, and progressively higher values of the progressively younger groups. Neither of the curves appear to have flattened. From the inclination and degree of curvature of the graphs thus obtained it is apparently indicated that these evolutionary changes are still in progress, particularly the decrease of generic coefficient.

EVIDENCE BEARING ON AGE AND ORIGIN OF THE HAWAIIAN SUB-FLORAS

The Hawaiian dicotyledons excluding those brought by man, appear to have come mainly from or by way of the Central American region. The affinities of the second wave with American Lower Eocene seem particularly clear, and this, together with the fact that the tribes to which the genera belong have their center of origin in the same Central American region as the Lower Eocene fossils are found is apparently indicative of the time and source of the second immigration of plants to the islands.

The first wave of immigration, as already explained, must have occurred at a considerably earlier period than the second; otherwise it would not be possible to account for the relatively great difference in age of these sub-floras which is apparently in every character where comparison is possible, and in that geological conditions, during Jurassic-Comanchic time, as will be dis-

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cussed presently, were favorable for dispersal of American plants over the Pacific, it is not improbable that the first immigrants may have arrived at this period.

A large proportion of the Hawaiian species which appear to have originated from the second period of immigration, have their closest existing relatives in the region of the East Indies or Australia, and this has been generally accepted as evidence of the Austral-Malaysian origin of the Hawaiian flora. The true affinities, however, appear to be with the Lower Eocene flora of the region of Isthmian America extending from the latitude of the Lower Mississippi Valley to the Amazon region of South America. From this region the Hawaiian representatives, on the one hand, and their close Indo-Malaysian relatives, on the other, seem to have had a common origin. With the subsidence of wide areas of Central America in Eocene-Oligocene time, the equatorial currents of the Atlantic must have continued westward over Central America into the Pacific, probably changing the direction and rate of flow of the Pacific currents in a way favorable for the dissemination of Central American plants to the Hawaiian islands and to the East Indies or even the shore of Australia, Asia, or the islands of the Indian Ocean. The distribution of the Begoniaceae and of Trevesia among the Compositae, and of numerous other plants bear out this supposition in detail. The Hawaiian sub-flora originating from this period of dispersal may therefore be regarded as a relic of Central American Lower Eocene flora and to have been dispersed under conditions existing at that time.

The most ancient position of the Hawaiian flora, however, is of considerably greater age than the sub-flora assumed to have arisen from dissemination in Lower Eocene time and must therefore have reached the islands at a correspondingly early period. According to Professor Schuchert, the Central American region was open again in Jurassic time, and, continued through Comanchic to Cretacic time. The affinities of this sub-flora and its relatively great age as indicated in every character, are quite in harmony with the supposition that the ancestral immigrants must have reached the islands at this time, and under the geological conditions of these periods. Under such conditions, it is easy to understand how a single ancestral immigrant from the Mediterranean-Canary island branch of the Prasioideae could have reached the Hawaiian islands by way of Central America;

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land connections between Africa and South America would have facilitated dispersal from this region.

If, as the evidence indicates, the first immigration of Hawaiian angiosperms occurred at this early time, then such highly specialized families as the Compositae and Campanulaceae must then have been in existence. But with the center of origin of these families in northern South America, close to the region of trans-Pacific dispersal it is evident that such plants would find their way to the Hawaiian islands early in their history; probably therein lies the explanation why an extraordinarily large number of immigrants—10 in number—should belong to these two families. (See table on previous page.)

Chances of dispersal were probably more favorable during the early period. The Gymnosperms were then predominant; the wood is of low specific gravity and floats for long periods; the stems reach large diameter and are favorable for the lodgement of seeds. Hence it follows that even though the angiosperms were subordinate in the vegetation and confined to the interior uplands, it is quite as one would expect that many would be carried over.

At the time of the second dispersal, on the other hand, the Angiosperms were predominate on the continent, or at least they had invaded the lowlands and littoral regions. But inasmuch as the woody stems in most cases, sink in water or soon become water logged, there must have been little drift which would remain floating any great length of time; hence a correspondingly small opportunity for seed and other life being carried in drift. The great predominance of angiosperms, however, would, to a certain extent, compensate the lack of chance.

SUMMARY

The Hawaiian dicotyledons appear to have originated in large part from Isthmian America.

During their geological history, two periods of dispersal are distinguishable, the first occurring at some time during the Jurassic-Comanchic-Cretacic submergence of the Central American region; the second, during the Eocene-Oligocene submergence.

Ocean currents bearing seed-containing drift appear to have been the chief agency of dispersal; and in so far as gymnosperms, the wood of which is extremely buoyant, were predomi-

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nant in Jurassic-Comanchic time, American seeds and other life must have been more generally dispersed over the Pacific during the first inundation of Central America.

The Hawaiian sub-flora originating from the inundation of Central America in Jurassic-Comanchic time is probably one of the most ancient existing Angiosperm floras and indicates the correspondingly great age of the Hawaiian islands.

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THE ORIGIN OF THE HAWAIIAN FLORA AND FAUNA

By F. Muir

The question of the origin of the fauna and flora of the Hawaiian islands is of very great importance on account of its bearing upon many questions relating to the Pacific. The first great question that confronts us is as to the status of the archipelago; is it entirely oceanic or has it been joined to a continental area? A correct answer to this question would clear up many problems in the far south as well as in other parts. If it be oceanic, we should look for a cosmopolitan fauna and flora drawn from various quarters of the Pacific; should we decide that it is continental, then we should expect to find a more homogeneous fauna and flora drawn chiefly from one of the continental areas bordering on the Pacific and closely allied to it.

On this point there is a difference of opinion and the evidence is conflicting; so all we can do at present is to submit the evidence and views of the different workers and see where they will lead. Personally, I can speak only from the point of view of an entomologist, but the evidence presented by the study of insects convinces me that the islands are oceanic.

A review of the insects of the Hawaiian islands and their nearest allies shows that they are drawn from all sides of the Pacific, except the north and northeast. In some cases the species of a single genus have two distinct origins. The hymenopterons genus Odynerus is an example of this. Dr. Perkins, who is an authority upon this group and who has devoted considerable attention to the Hawaiian species, has shown that they form two groups, one of which has close relationship to Oriental or Japanese forms. If we examine the different families represented in the islands, a dual or plural origin is often recognizable. The family Delphacidae of the Homoptera can be cited as an example. Here we have two groups; one consisting of species at present placed in the world-wide genus Kelisia, and the other consisting of some eight genera which until lately, were considered to be found only in the Hawaiian islands. In the Kelisia there is one species (*K. paludum* Kirk) which is also found in Fiji, Australia, Malay Islands, Ceylon and Philippine Islands. The endemic genera are divided into two groups which I consider have little connection with one another. The ancestors of one group arrived in the islands very much earlier than

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the ancestors of the others. In the older group there is one genus (Nesosydne) which is now known to have representatives in the Galapagos islands and in St. Helena. Such examples could be multiplied but a list of names would be of little interest on this occasion. To those who are interested in this question I refer to the Introduction of "Fauna Hawaiiensis," where the "waif and stray" nature of our insects is well shown.

The first thing to attract the attention of an entomologist starting on the study of the Hawaiian insects is not the insects which compose the fauna, but the insects which are missing from it, and it is this great, outstanding feature that must be accounted for rather than the presence of certain insects in the islands. As an example I will cite the case of the Lamellicorn beetles, the great group to which the May and June beetles belong. This group is known from all over the world, but is represented in the islands by only a single genus belonging to the Lucanidae or stag beetles. Now the larvae of Lucanidae live in wood, both sound and rotten, and could therefore be transported over sea, whereas the larvae of all the other Lamellicornia live in soil and could not be so carried. These insects are too heavy to be carried by air currents and are poor flyers. Another example is the "Tiger Beetles." The larvae of these live in holes in the ground and feed on living insects, which happen to walk by their home. Such larvae could not survive long journeys on floating islands, and as they are poor flyers and heavy, could not fly or be borne by air currents. Examples could be multiplied from each order, but I must refer the curious to the "Introduction" already mentioned.

In a broad way an analysis of our insects shows that those insects capable of flying, or being borne by air or water currents, are represented, but those not capable of being so borne are not.

Now if we erect a land bridge (and our insects would require several) to any one continental area, we have the enormous task of accounting for the absence of such large groups of insects. It is quite thinkable that during the long ages the islands have been in existence, combinations of circumstances could have brought the ancestors of our insects to these shores, but to me it is unthinkable that a land bridge, or several, could have existed and such large and predominant groups of insects could have been kept out.

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The geographical distribution of some of our insects is very strange. The genus Proterhinus has some one hundred and fifty species in these islands, and only one species is known outside, this one being found in Samoa. Did we derive ours from Samoa, or Samoa their's from us? The nearest relatives of this genus are in New Zealand, New Caledonia and the Canary islands in the Atlantic. I have already mentioned the case of Nesosydne (or Ilburnia, as we must now call it) being in Galapagos islands and St. Helena, but until the islands in the southern Pacific are more fully explored, it is of little use speculating as to the original home of many of our insects.

The means by which our insects originally came to Hawaii are difficult to state with any certainty. We are looking to other sections of this Conference to throw light upon this matter. We want to know more about the air and water currents of today and also what they were in the past. This latter will depend greatly upon the findings of the geologists and paleo-geographers. At present our "drift" is mostly from the northeast, but our insects show little affinity to those of Northwest America. Insects arriving from that locality would not find familiar trees or plants and would have great difficulty in establishing themselves. In the case of phytophagous insects, it is not only necessary that the insect be transported to our shores, but also that suitable plants should be established for them to feed upon.

One of the chief objections brought up against the flotsam and jetsam method of stocking these islands, is that many of the insects could not normally live on drift wood or similar bodies in the water. This is quite correct. If they could easily live on drift we should have a much richer insect fauna. But it is only by a combination of circumstances happening once in long periods of time that insects arrived, and that is why we have such a poor insect fauna compared with continental areas.

Our insect fauna is rich in moths, especially the microlepidoptera, or small moths. This group has great power of flight. Once when traveling between Hongkong and Java, when about two hundred miles from the coast of Cochin China, I noticed a great number of little moths flying about the ship. Some of them were very small, delicate insects with delicate fringe round their wings (plume moths as they are called) and I was surprised to find them in perfect condition. I suspected they were breeding on some vegetable substance on board. But I soon

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noticed that these insects were in great numbers all round the ship and all passing in one direction, from the northwest to the southeast, in the direction of the prevailing wind. Although the water was rough, many settled on the surface and rose again in perfect condition. We were going at right angles to the current of migration and it took about three hours to pass through them. Many of these must have eventually reached the coast of Borneo after a flight of some six hundred miles. Insects carried up into the upper strata of the air could be carried long distances before they would come to earth again. There are only two butterflies native to the Hawaiian islands. One (*Vanessa tammeamea*) is related to *Anosia phesci ppus*, whose wide distribution over the Pacific in the wake of its food plant (various species of Asclepias) has been recorded by J. J. Walker. He shows good reason to believe that this has been a natural migration. How many adventurous individuals went off into the Pacific before the white man had carried their food plants there, and therefore could not establish themselves, it is interesting to imagine. The second butterfly is a little "blue" (*Lycena blackburni*) which is of interest as it is the only representative of the group which has no glands on the back of the larvae. But then we have no tree ants to attend to the larvae and eat the secretion from the glands.

Although these remarks do not show the origin of the Hawaiian insects so far as phylogeny is concerned, they briefly state some of the facts which have convinced entomologists that the islands are purely oceanic, and have been stocked by waifs and strays from various parts of the Pacific. Only a much greater knowledge of the insects of other islands in the Pacific, especially of the south and southeast, will enable us to state with reasonable assurance from what part of the Pacific they came, and so enable us to follow their phylogeny, at least vaguely.

DISCUSSION

MR. MAYOR: Referring to the migration of insects on air currents, there is a good work by Dr. Ball of the Carnegie Institution written when he was stationed on Rebecca Shoal Light, forty miles from the Florida Coast. It is entirely surrounded by salt water. There is no land. When a wind blew from Cuba, ninety-two miles away, it brought a swarm of land mosquitoes. And not only mosquitoes but small gnats and flies, so that it is certain that an insect may be carried ninety-two miles over the sea.

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THE DISPERSAL AND AFFINITIES OF POLYNESIAN LAND SNAIL FAUNAS

By Henry A. Pilsbry

The mollusk faunas of the Pacific islands, marine as well as land, are related to the Eastern world, not to America. In the land and fresh-water faunas with which we are now concerned, no trace of American influence has been detected.

Travelling eastward from the Moluccas and New Guinea, which have faunas of continental type, we find similar faunas in the Bismark archipelago and the Solomon islands—large Helicidae such as Papuina and Choritis, large Zonitidae, Placostylus, the carnivorous Rhytididae, various slugs, the operculate Cyclostome snails, and others characterize these rich faunas, which malacologists, at least, will scarcely hesitate to consider of continental type. Further out, we come to the New Hebrides and Fiji groups. Here the Helicidae and many others have dropped out, but we still find large Zonitidae and Placostylus together with Rhytididae, the slug Veronicella, various operculate snails, large salt-marsh snails such as Pythia, and the fresh-water Mealnia and Ampullacera, also Batissa, a genus of large oriental bivalves. The presence of these groups, and especially the large, often ponderous Placostylus, led Hedley to view the Fijis, lying halfway between Australia and the Society islands, as the eastern limit of an ancient land which he called the Melanesian Plateau. The hypothesis that this area was once continental has been widely accepted. The evidence for it from other sources is now considerable.

Continuing eastward, we come into the island world of central Polynesia; the Cook, Austral, Society, Paumotu and Marquesas groups: scattered over about 1,700 miles east and west, nearly as large north and south. Throughout the high islands of this great area the land mollusk fauna is remarkably homogeneous. There can hardly be said to be more regional differentiation than there is in the Hawaiian group. The same or closely related genera extend throughout. For the greater part, these genera are also represented in the islands of the Melanesian Plateau, or are related to the latter. In these faunas Partula and Trochomorpha—like snails, carinate Zonitids, are the largest. These, together with small Zonitidae, Endodontidae, Tornatellinidae, Pupillidae, Succineidae, Realiidae, Georissa and Trunca-

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tellidae, chiefly compose the fauna. The fresh water Melania, Bullinus and the Cyrenidae drop out, as well as the large salt-marsh snails, Pythia and Cassidula. This may be partly due to the restricted fresh water stations. The minute Diplommatinids, almost universal eastward, are lacking.

A certain number of the small snails of the shore zone, such as Opeas, Tornatellina, Assiminea, and the Limax from Rarotonga and Tahiti, have doubtless been generally spread by native or later commerce.

There are certain special groups, such as Libera in the Cook and Society islands, Taheitia, Lamellorum; but all appear to be derivatives of more widely spread genera. Partula has been differentiated into recognizable subgenera in different island groups. *Partula hyalina*, of Tahiti, has also been found in the Cook and Austral groups. It is the only large land snail known to occur in more than one group.

How are we to account for this homogeneous fauna of minute high islands scattered over an area about as large as the United States east of the Mississippi? Was it by distribution over continuous land? Or was it by the occasional agencies of oversea drift, carriage by birds or by wind, bringing the snails to islands which have been built up singly and separately out of the abyss?

An answer to these questions at present can only be provisional. It is a matter of individual opinion, based largely upon our views upon geologic questions. If we believe with Schuchert, Iddings and others that there has been enormous subsidence in the Pacific, then we may reasonably entertain the idea of former land of continental dimensions or perhaps of a series of arcs, now and again connected, in the southern and western Pacific, if the faunal evidence favors that view. If, on the other hand, we start with the assumption that the distribution of land and water has always been as ill-balanced as it is today, that the present oceans beyond the continental platforms are roughly permanent, then the faunal evidence one way or the other becomes irrelevant.

It must be recognized that however the fauna was distributed, it would be so far homogeneous as to contain only families or genera represented in the land of its departure. I have elsewhere noted the fact that the fauna of central Polynesia contains primitive types common to the Fijis and to other islands westward. Also that the higher types of the Melanesian plateau are

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lacking. Dr. W. D. Matthew has called attention to the fact that the older a given group is, the longer time there has been for the chances of over-sea dispersal. While this is perfectly true, it does not account for the absence of dispersal in the later Tertiary, during the existence of Helicidae, Bulimulidae, Diplommatinidae and other high land snails in Fij and westward.

The argument for distribution of animals by natural rafts has never been more convincingly stated than by Mathew in his paper, "Climate and Evolution." Much of his argument, however, is not applicable to the Pacific islands. Here we have no large rivers like the Orinoco or Amazon to give forth natural rafts. If a single tree is washed into the sea it must be very exceptional. That such a tree would float 400 or 500 miles and make a good landing carrying snails still alive; that it would land in a place where the snails, Partula for example, would find congenial conditions, must be rare if it ever happens. The chances estimated by Mathew seem far too favorable. But in the present case we have to populate about 50 small islands scattered over two million square miles, with a varied population of shore and forest snails, partly arboreal, partly terrestrial, nearly uniform generically throughout, and characterized by the exclusion of modern groups of snails.

Every practical snail hunter knows how fastidious many forest snails are in the matter of station. Snails of the shore zone, such as the Auriculidae and Truncatellidae might readily find suitable conditions on a new shore; but forest snails such as Zonitidae, Endodontidae, Partulidae would not. A mammal bird or reptile once cast ashore, can make its way to a suitable station. No practical conchologist would expect an Endodonta, Amastra or Achatinella to do so. Unless we imagine a natural raft stocked like Noah's ark for each island, we must suppose a long series of happy accidents for each individual island.

Minute snails or the eggs of larger ones are doubtless carried by hurricanes for considerable distances; but where the distances are several hundred miles, it is doubtful whether such means have been effective. In the Hawaiian islands, it is clear that within the duration of existing species, there is no evidence of such adventitious distribution. The ranges of the species and their relationships to species adjoining are remarkably consistent. This appears to be true also of the Partulas of the Society Islands.

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Partula, one of the most widely spread Polynesian snails, is viviparous like the Achatinellas. The carinate groups of Endodontidae oviposit in the umbilicus of the shell. If carried by winds or birds, the entire animal would have to be taken. The forest ground-snails for the most part bury their eggs in moist soil or decaying vegetable debris. The chance of such an egg, carried aloft by the wind, falling in a spot favorable for its development appears remote. While natural rafts have doubtless played a part in the dispersal of mollusks as well as of other animals, and winds have carried snails over the sea, it appears to me that these hypotheses are seriously strained when applied to Polynesia. There are too many of the same genera on widely remote islands.

It appears to me that another hypothesis accounts for the facts in a more credible manner, and at least deserves further investigation. According to this hypothesis, the mid-Pacific groups from the Cook Islands to the Marquesas are viewed as remnants of a fragmented continental mass, possibly two-thirds as large as Australia, and this land was connected with the Melanesian Plateau before the latter was occupied by the higher groups of mollusks. This Polynesian land persisted as a large island or series of island arcs after the connection westward was severed, and finally broke up in the last half of the Tertiary.

Such an hypothesis accounts for the homogeneous fauna over widely scattered islands, and the absence of modern families and genera.

In the Hawaiian islands we have a fauna showing many analogies with that of other parts of Polynesia. The dominant families are more or less highly specialized land snails of a low group, the Orthurethra. As elsewhere in Polynesia, modern groups of snails are absent. There is a rich fauna of Endodontidae and small Zonitidae, an extraordinary development of Pupillidae, Tornatellinidae and Succineidae, with endemic genera. There are no land operculates except Helicinidae. Achatinellidae and Amastridae replace the Partulidae of the southern islands. Melania, Lymnaeidae, and the special genus Erinna represent the fresh water mollusca.

There is clearly nothing in this to suggest direct connection between Hawaii and the Polynesian islands farther south. Of the two faunas, that of Hawaii is surely more

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antique. The common elements of the two appear traceable to derivation of both faunas from rather similar ancient continental sources.

DISCUSSION

MR. SAFFORD: Is it not a fact that none of the mammals of Australia or New Guinea are found in these Islands?

MR. PILSBRY: Yes, that is true.

MR. MAYOR: One factor that we often neglect to consider is that very few scientists have lived in the place they are studying. The natives of these islands are great navigators and did not hesitate to go on voyages of several weeks' duration, and, when they did, they took with them taro and bananas and a great supply of food wrapped in banana leaves. Now these are the plants where the Partula is most often found. There is no mystery in connection with the wide distribution of this species. I have seen it all over Tahiti, but we don't find it at Moorea because the natives going there do not supply themselves with food. The distance is short and they know they will find plenty of food there. Again we do find it in the Australs considerably separated from the other islands. The native custom is to take food enough for about three weeks in their canoes. They go ashore on some island when this food supply is exhausted. That would explain the fact that the Partula is found practically everywhere. It is evidently the result of migration from the Malay Archipelago through various islands to Rotuma and from there to Samoa, to the Cook Islands, Tahiti and New Zealand. The islanders were very venturesome sailors, and as we know they took voyages of long duration to the Hawaiian islands from the Society Islands and Tahiti.

Moreover the time required for the evolution of the Partula is not great. New species can be produced very quickly. Crosses between two species will produce a new species not seen before. Of course I will admit that a place like Fiji may have been connected with New Caledonia and New Zealand. But it seems improbable that a large continent could exist in the midst of the Pacific and have no mammals but only lizards and snakes which could easily have been carried across the sea on logs or brought by the natives for religious purposes.

MR. PILSBRY: I am very much gratified to hear this explanation of the distribution. I had already, although I had no special knowledge of conditions on those groups, made the supposition that the shore shells in Hawaii had been distributed by natives on native voyages. As to the rapid growth of species, I think there could be two opinions. Now the Society Islands Partula all belong to a single section. We separate them from closely related species and it is a matter of hair splitting whether they are species. It is a matter of opinion. The mutations which appear are the same as those in the Hawaiian islands. Their color mutations are of little value. Every species goes through a kaleidoscopic series of changes in a short time. But on the different groups of Polynesia we find the Partula somewhat more differentiated. We divide them into sections. The Marquesas Islands, Society Islands and Samoa each have their own genus. They go back a long way. Now in places where we know something about the history of the land, in North America and northern Europe we find that practically all the modern species reach back into the last geological period, and in America we know that quite a number of modern species in Florida are found in the Pliocene period. While color mutation goes on rapidly, real structural change takes place slowly. In the genus Cerion a remarkable change has been brought about by hybridization, but changes are small. Some people admit only one species, some

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a dozen, so that they cannot be the explanation of the differentiation of the species that has gone on between the islands of the Pacific.

MR. BARTSCH: From what Dr. Pilsbry said about Cerion one might be led to believe that shell characters only had been considered. If this were true, then we would be today exactly where we were when we began our breeding experiments in 1912.

It was the close resemblance of the shell which was responsible for my referring in the early reports to forms used in our experiments, simply as the King's Road and the White House type of *Cerion glans*, these names being derived from the localities from which our stock was obtained on Andros Island, Bahamas.

The fact that they would not hybridize prompted an anatomical examination, which showed that these two forms were so different in their anatomical structure that it is not at all surprising that no crossing had been effected. I am sure Dr. Pilsbry would not only have considered them distinct species but would have placed them in separate groups on account of these divergent characters and yet I am of the opinion, judging from some of our breeding experiments that they are of rather recent origin. I am inclined to believe that the entire *Cerion glans* group was evolved by hybridization in Pleistocene time when the Bahama Islands formed a connected land mass. At this time the group was enabled to spread around the entire land area. Later when the melting of the glacial ice caps returned water to the sea an interrupted distribution ensued which finally ended in the formation of the many colonies we have today, each occupying an extremely local area. The members of each of these colonies appear to possess certain characters peculiar to that colony, produced by internal and external adjustments which have resulted in the final fixation of stable characters.

Our crossing of the Bahama *Cerion viaregis* with the Floridian *Cerion incanum*, two very unrelated forms, has produced no end of forms, many with entirely different characters than either parent stock possessed. All this fluxing has been produced within two generations and if fixation can be equally speedily affected then it seems that the question of a long time element for the production of new forms is not at all necessary. In fact our experiments would rather argue for saltation than for an infinite time element.

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HAWAIIAN FAUNA AND FLORA

By William Alanson Bryan

I have just returned from a rather extensive journey along the Pacific Coast of Central and South America and to Easter and Juan Fernandez Islands and have not yet had time to put my observations into final form. This presentation should therefore be regarded as preliminary.

The origin of the fauna and flora of the Hawaiian islands is involved in the larger question, the origin of the life in the Pacific islands. The available data are not yet sufficient to permit a clear and satisfactory solution. As Dr. Pilsbry says, it is impossible to think that the land mollusca inhabitating the group arrived here by chance, or that they have been carried by the wind, or attached to birds' feet or have floated here over two thousand miles of open ocean. And having once arrived here it is impossible for them to have attained present distribution through the islands by any means except that of crawling on their own stomachs from one end of the group to the other. Such observations call for the existence of former land connections which have since sunk beneath the sea, leaving the groups of islands as we know them today. Moreover there is abundant physiographic evidence, as I have elsewhere pointed out, that bears out such a theory of submergence in the group.

Dr. Muir and I have discussed the migration of insects at various times and I agree with him fully that at least a large part of the insect fauna of the Hawaiian group might possibly have arrived here from time to time wind-borne or water-borne. However, I personally regard the insects as of little value in a study of the origin and former connection of our land faunas. Only a day or two ago Mr. Swezey informed me that 26 species of insects had been reported by our entomologists established in the islands within the past few months. How they got here is not known. But such an illustration is enough to show that insects have many means of reaching these isolated islands and for that reason are of little value in an attempt to answer the question involved in the origin of the fauna as a whole.

I have listened with more than usual interest to the discussion here on the origin of our plant life, and it seems to

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leave in my mind as I believe it does in yours, the feeling that it is necessary for us to have some additional investigations in and about the Pacific in order to account for the origin and dispersal of the plants.

When you turn to consider the existing marine fauna of our Hawaiian waters you will find that all of the zoologists who have worked on it are inclined to think that our marine animals are closely related to, in fact a part of the Indo-Pacific region rather than derived from the American faunas. This too in spite of the fact that the winds and the currents as they exist today set from America and not from the Malay Straits.

Turning to the land again we have in Hawaii a family of birds (Drepanidae) that have no very close relations with any other existing family. Dr. Gadow who has studied their anatomical characters is inclined to think that they are distantly connected with the Tostropidae of Central America. They are however very different in their habits and are not closely allied with them. Moreover this Hawaiian family is broken up into a number of widely diverging genera and numerous island-bound species; so much so that the Zostrops may have had their origin from our fauna rather than our fauna having been derived from Central American sources. Our genus of Chasiemphis on the other hand has its relatives in the old world; Australia for example may have supplied this species to the Hawaiian islands.

It would seem that during the long period of time that the islands of the Hawaiian group have stood so close together—within sight of each other—the birds above all animals, would be able to move freely from one island to another and thus keep its stock uniform. But we find that this peculiar family is broken into genera and the genera into island-species inhabiting only one restricted region or valley. From the breaking up of this group we have in one genus (Oriomistis) a red species in the middle of the group, a greenish one on Kauai, a yellow-green one on Maui and a brownish one on Hawaii and so on through the several genera.

My opinion is that we may have to look further back than the Cretaceous period to find the origin of at least part of the Hawaiian fauna and flora because of the slow processes of evolution. If we attempt to trace out relationships in all fields

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we are going to find, as Dr. Brown points out with the flowering plants, that there is a wide difference in the relationship of the different groups, often extending across and throughout the Pacific, which indicates to me that there must have been very different conditions prevailing in this ocean in ancient times, with land areas and ocean currents far different from those existing at present.

Rather than regard our Hawaiian fauna and flora as growing up on the islands as an accidental accumulation on a highly isolated volcanic group of barren islands I prefer to believe that these islands have had some land connections, or bridges, and all my study and observation confirm me in that opinion.

These animals and plants must have come from somewhere, and I feel that when we get the relationships and connections worked out we shall find that they have had some definite connections with older continental areas. My feeling is that with Cretaceous coal on the island of Mocha off the coast of Chile, coal in Australia, coal in New Zealand and coal on the little isolated island of Rapa in the middle of the South Pacific we are going to find that more of our plants and animals have originated in the then warm regions of the Antarctic when these regions were doubtless more closely connected than some are now inclined to believe.

I have just returned from Juan Fernandez Islands and Easter Island. The anthropological and biological interest afforded by remote Easter Island almost overwhelms one. This island is but 13 miles long by 7 miles wide and is made up of the remains of three large craters, one in each angle of its triangular outline of the island. On the slopes of these are thirty ash cones of varying sizes. Easter Island appears to have been at a standstill as far as elevation or depression is concerned ever since it rose above the surface of the sea. The long crater slopes have vertical sea cliffs a thousand feet in height, indicating the vast time the island has stood as it is now.

The land animals are exceedingly few, the bulk being insects, a group which unfortunately is of little value in tracing origin or relationships. Most of the species both plant and animal have arrived at the island since it was visited by Europeans. On this island I found no land shells with the exception of one species which appears to be very closely at-

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tached to the plant which the primitive Polynesians carried there, according to their legends, for the purpose of making tapa. Of the total list of about 134 species of plants one half have been recently introduced while a number originally found growing on the island, were introduced by the natives themselves even as here in Hawaii. Of the entire list of native plants scarcely one is sufficiently differentiated from near relatives growing elsewhere to make it worthy of a specific name. They all seem to belong to widely varying forms capable of being carried either by wind or by water; yet the island has stood as it is for countless ages as shown by its sea cliffs As it stands it is a fine example of an isolated oceanic volcanic island that has gathered its fauna and flora from accidental arrivals and thus differs greatly from Hawaii. Its land life is as much South American as it is Polynesian.

On the other hand, curiously enough, all the marine animays I was able to collect or observe about the shores of the island have definite affinities with Polynesian and even with Hawaiian fauna. This too in spite of the fact that the currents and winds are from the South American shore much as ours here in Hawaii are from the North American coast. This was not a great surprise to me even though the nearest Polynesian island of any size is more than 1500 miles to the westward, and migration from there would be against the currents and winds. It was what I expected and the reason for expecting it I shall attempt to explain in another connection at a later time.

I went next to the Juan Fernandez Islands where different conditions were met with. The group is composed of two islands. I first visited the outlying one (Mas Afuera). It is ninety miles from Mas Aterra and is six miles in length by three in width and attains an elevation of about 6000 feet. On its eastern side are more than twenty valleys, cut down until their valley floors rise at a grade of ten percent so that at the valley heads you look up 4000 feet at the valley walls. Many of these valleys are so narrow that the sun scarcely ever reaches the bottom.

I found land shells on that volcanic island which more or less closely resemble those found here and are doubtless of Polynesian origin. I found also a well developed flora closely related to that of the larger island (Masa-tierra) which

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extended in almost every case from the shore to the very summit. In Hawaii we usually get quite different plants at different elevations. It was a singular and significant thing to note the wide range of plants which inhabit that island.

The other island, generally referred to as Juan Fernandez, undoubtedly the last remnant of a submerged volcano, is thirteen miles long, three and one half miles in the widest part, and attains an elevation of 3000 feet. On this island are 60 endemic species of plants many of them very similar to those in Hawaii. I almost lost myself in the mountains under the impression that I was in the Hawaiian woods. That is, I found the animals and plants and their associations and the general conditions of climate very similar to that found here under similar conditions.

The object of my long journey was to test out a theory. As some of you know my wife and I were interested in the study of Hawaiian mollusks. Prior to her death we had discussed the origin of our shell fauna and had come to the conclusion that if the land shells of Juan Fernandez were at all related to those of Hawaii the fresh water shells, should there be any, would tell even more of that relationship, for reasons that I need not enlarge upon here. Knowing that the Juan Fernandez land shells had at least a superficial resemblance to those found here, I thought that it might be worth while making alone the long journey we had planned making together, in order to study the matter carefully on the ground.

Curiously enough I found no fresh water fauna or flora peculiar to that island, although there are a few permenent streams. Still more peculiar especially in comparison with Easter Island is the fact that the animals about its shores are all of South American origin, with the possible exception of the large lobster for which both islands of the Juan Fernandez group are famous, but which does not live on the Chilean coast only 390 miles away.

When one goes as far as I did to find a thing and does not find it he naturally seeks an explanation. It seems to me, from the many different types of indirect as well as direct evidence of submergence that I found there, that there has been profound submergence in that group sufficient enough to cut these two islands apart and isolate their plants and animals. Be it remembered in this connection that these islands were

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never inhabited by a primitive people and that their winds and currents pass between them and not from one to the other. Personally I am just as satisfied that the whole of Juan Fernandez archipelago went down in a sudden cataclysm as though I had stood by and seen it go. In no other way can you account for its curious mixtures of old land faunas and floras; its marine faunas and its absence of fresh water life. But we want more data. For example, the fishermen tell me they fish over the swirl of water which they believe to be caused by a submerged ridge between the two islands. Moreover they report bottom off shore six to ten miles in several directions in from sixty to ninety fathoms of water.

When I found there a species of Gunnera differing from another species on an island only ninety miles distant and both apparently in the process of still further evolution with the prospect of a submarine ridge connecting the two islands I put it down as pretty good evidence of submergence. When I know that Gunnera also occurs in the Hawaiian islands 6000 miles away I consider it also as an indication of submergence rather than accidental introduction, and so on through a list of connected or related observations both here and there.

When we get to the bottom of this whole matter and the data is finally in, I feel that we shall find there has been a widespread and general submergence in this whole vast region.

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SOME PROBLEMS IN HAWAIIAN ENTOMOLOGY

By F. Muir

The chief object of this Conference is to bring together scientists interested in problems of the Pacific with the object of cooperation and mutual assistance. Scientists from the earliest times have formed a brotherhood and entomologists all the world over have banded together for the advancement of their own particular studies.

The Pacific is a huge laboratory where nature has carried on huge experiments in migration, segregation and species formation for enormous periods of time. To understand fully the various processes which have brought about the present entomological conditions in the Pacific it is absolutely necessary to know the conclusions arrived at by workers in other branches of natural science, and to trp to coordinate all our knowledge to form one harmonious plan. This ideal may never be attained but we have to work towards that end.

Entomology, both scientific and economic, is further advanced in Hawaii than in any other islands in the Pacific. It dates back to 1793 when Fabricius, in volume II of his celebrated work "Entomologia Systematica" described two Hawaiian Hymenoptera, *Odyneurus radula* and *Ichneumon fuscota*, collected by Capt. Cook in 1778. Subsequently other early circumnavigators called at the Hawaiian islands and collected a few insects. But we had no adequate idea of the unique fauna until 1876 when the Rev. Thomas Blackburn came to the islands. He resided in Hawaii until 1882 and during that time collected in all the main islands but chiefly around Honolulu. Alone and in conjunction with Dr. David Sharp he described many new species and genera, and other specialists described some of his material. This work roused the interest of naturalists of Great Britain and in 1890 the British Association for the Advancement of Science appointed a Committee "to report on the present state of our knowledge of the Sandwich Islands, and to take steps to investigate ascertained deficiencies in the fauna, with power to cooperate with the Committee appointed for the purpose by the Royal Society, and to avail themselves of such assistance as may be offered by the Hawaiian Government or the Trustees of the Museum at Honolulu." Dr. David Sharp was appointed secretary and

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Dr. R. C. L. Perkins was chosen as field explorer. At a later date the Bernice P. Bishop Museum cooperated in the work, and many specialists worked on the material collected. The results of the labors of these men are embodied in the three large volumes of the "Fauna Hawaiiensis." Apart from this work the Proceedings of the Hawaiian Entomological Society contains most of the information published on the insect fauna.

All this work was purely systematic, consisting of collecting and classifying the insects of the archipelago. The economic aspect was never considered. But no activity of the Bishop Museum has been of greater economic value to the territory than its coöperation in the preparation of "Fauna Hawaiiensis" for this work forms the basis of our knowledge of the peculiar conditions of Hawaiian insect fauna, the recognition of which has guided us in the economic work which has been of such great value to our chief industry. Unfortunately it has become popular in some quarters, even among zoologists, to belittle systematic work and to look upon it as holding an inferior position. Either through lack of knowledge or understanding the detractors of systematics are unable to see that it is the one branch of science which cannot be dispensed with since without it one is unable to speak or write on any branch of entomology with intelligence.

In the introduction to the "Fauna Hawaiiensis" Dr. Perkins has reviewed the insect fauna in a masterly manner and, with a commendable caution, has drawn certain leading conclusions regarding several of the main biological problems. For details I must refer inquirers to that work. The first problem with which we are faced in order to acquire a correct understanding of the origin of our insect fauna is the status of the archipelago. Is it purely oceanic or is it continental? The answer to this question will influence all our ideas. In the one case we shall conceive of our fauna as having arisen from a very few immigrants, the endemic families, genera and species having all arisen locally; in the other case we shall think of our fauna as being the remnant of a large and richer continental area.

The question cannot be settled by zoologists alone, nor even by biologists alone: all the evidence must be taken into consideration which geology, hydrography, geography, paleogeography and paleontology can bring to its solution.

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The evidence of entomology is overwhelmingly in favor of the oceanic theory. The most striking thing about the Hawaiian fauna is the absence of whole groups and the orders present are represented by only a few families which could have come by flight or by air or ocean currents. To give but a few examples: the whole group of the Lamellicorn beetles is represented by a single genus composed of a few allied species, of Lucanidae, and these are confined to the island of Kauai. The larvae of this family live in rotten or sound wood and could be carried in drifts. The great group of Scarabeidae, whose larvae live in soil and therefore are not likely to be carried in drift, and all of the Phytophaga, whose larvae feed on living leaves and therefore could not come on drift, are not represented at all. These beetles have small power of flight and are too heavy to be carried by wind. The Cincindelidae are also absent. Owing to their specialized habits their larvae could never arrive in drift and the adults could not fly or be wind-borne for long distances. To me one of the most interesting features of this Conference is the amount of evidence that has been brought forward bearing upon this subject; and the outstanding feature of the evidence is the strong support it gives to the oceanic theory. So strong, indeed, is that evidence that I shall consider it as conclusive until such time as the holders of the continental theory can bring forward stronger evidence in support of their theory. That there are cases hard to explain without land connections is possible, but the difficulty of explaining why so much is not here, if we postulate a land connection, is infinitely greater.

The argument for continuous land areas draws its chief support from geographical distribution and the supposed impossibility of certain forms passing over large ocean areas. Upon the last point I must insist on our vast ignorance. The data as to what is carried on floating islands and drift is very small and future expeditions should make careful examination of all such material met with. The amount of insect life washed down with "drift" during floods is enormous and is well known to the birds as well as to collectors. In Australia I have watched the birds patrol the river during floods and take toll from every passing log. It is not every insect washed out to sea that reaches a destination; but only one or a small colony, perhaps, out of the millions set adrift during long ages, survives. For this reason

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experiments to see if certain beetles could live in sea water are of little value.

The argument from the geographical distribution of genera is based upon the idea that the species of a genus are always of monophylatic origin. That this is so in the vast number of cases is no doubt correct, but I raise the point as to its universality. I will give two examples drawn from Hawaiian Homoptera which appear to break the rule.

Elsewhere[1] I have stated my reasons for considering the authochthonous genera of Hawaiian Delphacidae as having two distinct origins. The ancestors of these two groups arrived separately, one considerably before the other. Both have one character in common, viz., two distinct longitudinal carinae upon the face. Each has given rise to parallel genera having only a single carina on the face. I believe that the genus Nesosydne Kirk arose from Aloha Kirk within the islands. While working over the Delphacidae in the British Museum I found two specimens from St. Helena described by White under the genus Ilburnia which are congeneric with Nesosydne, so I had to sink the latter: there were also two species described by Walker under Delphax from the Galapagos islands which, although not so entirely typical, have to be placed in the same genus. In spite of this disconnected geographical distribution I still hold that the Hawaiian species Nesosydne, or rather Ilburnia, arose locally from Aloha and have only an indirect connection with the species in Galapagos and St. Helena through a widely distributed ancestor closely allied to Aloha if not identical with it.

The second example is taken from the Chermidae (Psyllidae) or Jumping Plant Lice. The genus Kuwayama Crawford differs chiefly from Trioza Foerster by the absence of genal cones. Crawford[2] considers that the three Hawaiian species of Kuwayama have no direct phylogenetic connection with the species of the same genus in other parts of the world, but arose locally from a local Trioza, possibly *T. ohiacola*.

Although such cases may not be very numerous, yet I believe they will be found to be numerous enough to be taken into consideration when discussing geographical distribution and land areas.

Another strange case of goegraphical distribution among the Hawaiian Delphacidae is that of *Kelisia paludum* Kirk. This

[1] Pro. Hawaiian Ent. Soc. III, 3, p. 168, 1916.
[2] Loc. cit. III, p. 445, 1918.

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insect was originally described from the islands and considered to be endemic, but during my travels in the Pacific I have taken it in Fiji, Australia, Java, and the Philippine islands and have specimens from Ceylon and India. A study of this insect in its various habitats may show that it has been disseminated by man's agency, along with several plants, and perhaps insects, from the Indo-Malayan region.

When we inquire as to the manner in which the insects arrived in Hawaii we must turn for information to the meteorologist and hydrographer, for the currents of air and water were the chief agents. It is not enough to know how these agents are acting at the present time; one must have some reasonable idea as to how they acted in the past. And here we have to turn to the geologist and paleogeographer. The main currents of air and water are the outcome of physical agents which have acted from the time when the earth took upon itself its present form, but they have been modified by the relative position of land and water. When the land barrier between North and South America was broken down the tropical ocean currents must have been greatly altered. If the coast of northwest South America or west Central America was extended to the northwest, as is postulated by some geologists, then the present currents along the coast of America must have been greatly altered and directed towards the Hawaiian islands. The raising of the Polynesian plateau would also change the present currents considerably. Any or all of these modifications might have made it much easier for insects and plants to have reached the islands.

Dr. Forest Brown in his interesting paper on the "Origin of the Hawaiian Flora" stated that 30 seeds arriving at the rate of one in a million years would account for most of the endemic plants. It would require a slightly higher number of insects to account for the insect fauna. He also stated that the genera in which there were many endemic species, and which are therefore probably the most ancient, have small seeds. Broadly speaking we could parallel this in the case of the insects, with a few exceptions.

In the field of evolution the islands offer some interesting problems; for here a great number of species, many genera and some families have been evolved under conditions more simple (and therefore more likely to be within the understanding of the human mind) than we can hope to find in any other part of the

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world. There are no reasons to suppose that biological conditions in the islands were ever any more complex than at present; in fact it is likely to have been otherwise.

A study of many of these species indicates that natural selection has played little or no part in the origin of the endemic insects. Many of these are mainly phallic species in which the body (or chrootic) characters have differentiated very little but the male genitalia have differentiated very distinctly and considerably. Elsewhere[3] I have put forward some evidence to support the suggestion that the external male genitalia are the first portion of the insect to reflect any alteration of the germplasm. In other cases (i. e. *Ilburnia cyathodis* and its varieties),[4] we have considerable chrootic differences which might even be considered of generic value with practically no difference in the genitalia. I cannot conceive of these phallic differences being of any selectional value, but having once risen they may be of value as a form of isolation.

Gulick has shown the value of isolation as a factor of differentiation of land shells. The study of the insects leads to similar conclusions. But if hybridization, or the mixing of the chromosomes, at each generation is the only or chief cause of variation, then should not any restriction of crossing by any form of isolation limit variation? If so then large continuous areas with little or nothing to impede migration should be favorable to variation and areas unfavorable to migration, such as mountains and islands, should be the reverse. But this is contrary to all experience.

This is not the place to dwell upon the economic entomology of Hawaii except in so far as it reflects upon wider scientific questions. All of our insect pests are introduced and our chief method of combating them is by the introduction of natural enemies. Along these lines we have been strikingly successful, owing to our unique biological conditions and our knowledge of them. Without the systematic work previously mentioned we could only have worked in the dark; we should not have known whether a pest was a native of the islands or an introduction.

During the last twenty years a great deal has been written on the death factors of insects but mostly along two lines. First a long list of captures has been recorded and experiments on feeding animals with insects have been made. These have been

[3] Loc. cit. III, p. 210, 1916.
[4] Loc. cit. IV, 1, p. 91, 1919.

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of great value and have shown us that certain insects are attacked by certain enemies, but they have given us but little insight into the effect such predatory insects might have so far as natural selection is concerned. The second line of investigation has been on injurious insects, mostly where they are very numerous, and therefore free from any great struggle for existence.

In our search for enemies to control our insect pests we have had to study the pest over wide areas where it is held in check by natural agencies, sort out various death factors and experiment with them in the Hawaiian islands. The sugar cane leaf hopper (*Perkinsiella saccharicida*), and its allies have now been studied in Fiji, Australia, New Guinea, the Malay islands of Larat, Ceram, Borneo and Java, the Malay Peninsula, China, the Philippine islands, Formosa and Japan. These studies have taken several years and the observations have been made by several men. The result is to demonstrate that the death factors acting upon these insects are similar in all these regions and that it is the eggs and the young that are destroyed up to as high as 90 to 95 per cent, leaving only 8 to 3 per cent of the adults to fall in the struggle for existence. By introducing some of these factors into our islands and getting similar results to those we find in their native habitat we have demonstrated that these are true death factors. Such experiments carried out on such an extensive scale have to be considered when we discuss the action of natural selection on specific characters. From this point of view our economic work is of great value to biology, for our experiments have been carried on on a larger scale than anywhere else.

The above is but a little of the evidence contributed by Hawaiian entomology towards the solution of some of the problems presented by island life in the Pacific. Unfortunately the vast majority of the Pacific islands at present can produce little entomological evidence toward the solution of these problems as the fundamental work of collecting and identification has not been done.

When one considers how rapidly the natural conditions of so many of the Pacific islands are being swept away by the requirements of modern civilization, one cannot advocate too strongly the immediate prosecution of this work. The manner in which the entomological work in the Hawaiian islands has been done

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presents a good example of how it should be done elsewhere. Investigation carried on upon purely scientific lines has resulted naturally in immense economic advantages. To try to reverse the method would, I believe, be less satisfactory.

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SOME ASPECTS OF HAWAIIAN ENTOMOLOGY

By O. H. Swezey

In presenting to the Conference the importance of entomology in the Hawaiian islands and outlining some of its more salient features, let me say at the start that coming as you have to this so-called "Paradise of the Pacific," those of you who are interested in insects will soon find that this is no "Paradise" for the insect collector. The visitor who has seen or read of the large and showy insects and gorgeous butterflies that have been taken in some groups of tropical islands of the South Pacific, knowing that Hawaii is situated in the tropics, and therefore expecting to find much the same display of insect life here, will be sadly disappointed when he goes into our valleys and mountain forests in search of showy desirable captures.

On the lowlands and cultivated districts, there is apparently a great sufficiency of insect life. The gardeners and agriculturists complain that there are more insert pests here than anywhere else in the world. There certainly are plenty, both in kind and in the number of certain kinds that may be present per plant or tree. There are scarcely more, however, than are usually found in cultivated regions. With very few exceptions, these pests, together with many insects of no economic importance occurring on the lowlands, do not belong to the native insect life, but are immigrants from other parts of the world which have arrived here by some natural means or through the channels of commerce. A goodly number have been purposely introduced of recent years by reason of their being parasites or predatory on those which are pests.

Thus there are two distinct classes of insects as regards their origin and their scientific interest. The scale insects, plant-lice, and other garden and crop pests; the flies, ants, roaches and other domestic insects about our houses, are chiefly immigrants which have arrived here since the coming of the white race to the islands. On the other hand are the really native insects which have developed here through long periods of time, and which are much more numerous in species than the immigrant insects, though much fewer in number per species, and are rarely seen by any except the enthusiastic entomologist who by surmounting many difficulties, and by diligent search in the moun-

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tain forests is enabled to find them in small numbers. To be sure there are a certain few native insects to be found on the lowlands which have not yet been supplanted by the immigrant species; but it takes one of experience and familiarity with the native fauna to distinguish between these and the ones which are immigrants.

On account of these two classes of insects (native and immigrant) we have two phases to entomological work: economic entomology dealing with the insect pests and their control, and the study of the native insect fauna which has been found of great interest in many lines. The work of the economic entomologist has been very successful along the line of studying immigrant insect pests in their homelands, and introducing to Hawaii such parasites or other natural enemies as were found efficient there in keeping the pests in check. This kind of work dates back to 1893-1900 when Mr. Albert Koebele, working alone for the Board of Agriculture introduced many valuable lady-beetles and other beneficial insects from Australia and elsewhere. Later on this kind of work was taken up more extensively by the Territorial Board of Agriculture and Forestry and by the Experiment Station of the Hawaiian Sugar Planter's Association, until at the present time no less than a dozen trained men are engaged in one phase or another of economic entomology.

Some of the successful accomplishments of this group of workers in the line of introducing natural enemies for insect pests have been the introduction of a dozen or more ladybeetles and numerous hymenopterous parasites to prey on plant-lice, mealybugs and scale insects; army-worm parasites, leafroller parasites, egg-parasites, and other parasites on the sugar cane leafhoper; several parasites on the Mediterranean fruitfly and the melonfly; the New Guinea Tachinid parasite of the sugar cane beetle borer; the Philippine Scolia parasite on white grubs; and others of minor importance. A recounting of the travels and experiences of the entomologists when in search of these parasites is a long interesting story by itself but cannot be included here. None of these parasites has exterminated the pest, but in most cases the pests are sufficiently controlled by them so that other means of control are not practiced.

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Not much interest was displayed in the native insect fauna until the Rev. Thomas Blackburn, who was connected with the Cathederal in Honolulu during the years 1876-1882, collected the native insects quite extensively in the mountains about Honolulu and sent them to England for determination. Mr. Blackburn's pioneer work revealed the highly interesting endemism of the Hawaiian insect fauna, and eventually led to the systematic exploration by R. C. L. Perkins, and the publication of "Fauna Hawaiiensis." This exploration was begun in 1892 and continued for about ten years, and constitutes the most complete entomological exploration of any group of oceanic islands that has yet been undertaken in the Pacific Ocean. As the result of this exploration, 3245 species of insects were listed in the "Fauna Hawaiiensis." 2740, or 84 per cent of the species were considered endemic. These were largely new species whose descriptions appear in the "Fauna." The book is a series of monographs comprising 2391 pages and 81 plates, many of them colored. The greater part of it deals with insects, altho the other classes of land animals are also included—chiefly the Mollusca, spiders and birds.

This work on the insects brought out the main characteristics of the native insect fauna, as well as indicating which families of the different orders are present and what prominence the different ones have in these islands. A brief review of these will serve to indicate to you what is to be found in the way of native insects in our native forests. It will not assure your collecting many of them, however, if you should wish to spend a day collecting in the more accessible mountain forests. One reason for this is that many species are attached to particular trees or plants and unless searched for on their particular hosts will not be found; and it often happens that this tree or plant does not occur in the particular place where one is collecting. The fact that many of the trees are quite limited in their distribution, is a factor of importance in determining the distribution of many of the insects of Hawaii.

Then, too, many of the species occur only on a single island. This feature is most pronounced on the island of Kauai separated from Oahu by a channel about 70 miles in width. Almost its entire insect fauna is peculiar to the island.

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The island of Hawaii is much the same, though not to so great an extent. The group of islands,—Maui, Molokai and Lanai,—are separated by channels of about 10 miles and have many species of insects in common, though each has quite a good many that are peculiar to itself, and they also have some that occur on Hawaii and Oahu respectively. Oahu thus has some species in common with the Maui-Molokai-Lanai group and also some in common with Kauai. There are a few which occur on all of the islands.

As an illustration of island distribution of related species, the banana leaf-rollers may be used. These are caterpillars of the genus Nacoleia (*Omiodes*). Six species are at present known to feed on the wild banana plants and probably there are more yet to be discovered. Four of these species are on the wild bananas on various parts of Hawaii, one on Maui, and the sixth species on Oahu and Kauai. In the same way there are lepidopterous leaf-miners on ohia lehua, *Pipturus*, and on many other trees which have different species of their respective genera on the different islands. Many similar examples could be given of the development of different species on the same host tree but on different islands.

Furthermore, many of the known species of Hawaiian insects are exceedingly rare, the description in the "Fauna Hawaiiensis" being based on a single specimen and no others having been collected since. For example: of the 440 species of Microlepidoptera, 25 per cent were described on a single specimen, and 41 per cent on not more than 2 specimens. Much the same situation prevails in other orders, showing that for about half of the species the chances are very small for a collector to obtain specimens.

On the other hand, some species are often found in unusual abundance: for example, a bark beetle (*Proterhinus angularis*) which may be collected by hundreds beneath the bark of dead Straussia trees; a large weevil (*Nesotocus giffardi*) considered rare, whose larvae I once found in hundreds beneath the bark of a recently fallen Cheirodendron tree; a leafhopper (*Ilburnia gunnerae*) found in great abundance on the leaves of the strange plant, *Gunnera petaloidea;* a Prionid beetle (*Parandra puncticeps*) otherwise rather rare, whose larvae were once found in large numbers in dead wood of *Acacia koa;* and of other trees. Such cases occur where

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the collector was so fortunate as to arrive on the scene at the opportune moment, when these dead trees were in just the right condition to be inhabited by the insects mentioned.

The foregoing is sufficient explanation of why an insect collector unacquainted with the islands will meet with disappointment on his first trip into the mountains, where instead of finding the tropical forest teeming with insect life, he will have to search well to secure much insect material.

The following review of the orders shows which families predominate in the Hawaiian fauna, and which important ones are entirely lacking.

The Hymenoptera are represented by 17 families, or about 18 per cent of the known families. There are 498 species, nearly half of which are Aculeates, and more than half are Parasitica. There are 53[1] native bees of the family Prosopidae. The native wasps belong to three families: Crabronidae with 18 species; Pemphredonidae with 10 species; Eumenidae with 104 species which chiefly belong to the genus Odynerus. Many species of the latter occur on the lowlands. They all store caterpillars in their nests in the cavities of lava rocks, borer holes in trees, burrows in the ground and in other situations. They serve a very useful purpose in the reduction of leaf-roller caterpillars, some of which are of economic importance.

There is but a single ant that is considered endemic. The other 20 species present in the lowlands are all immigrants, and a few of them are quite annoying about our houses, though we are not yet troubled with the notorious Argentine ant.

Of the parasitic Hymenoptera, Bethylidae is a prominent family with nearly 200 species, most of which are in the genus Sierola.[2] There are a few species of Proctotrypidae. There are 53 Cynipids, but none are gall-makers; they all belong to the Figitidae which are parasitic. Some of the families of the Chalcidoidea have a few species, the greater number falling in the family Encyrtidae of which the genus Eupelmus has 54 species. The Ichneumonidae are chiefly Ophionines with but 31 species.

[1] The figures here given are based on the "Fauna Hawaiiensis." A few species in some of the orders have been added since.

[2] Fullaway, New species of Sierola. Occ. Papers. B. P. B. Mus., vol. VII, No. 7, 1920.

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The Braconidae has one native species, but there are a good number of introduced species, both immigrant and those purposely introduced.

Coleoptera is much the largest order with 43 families, or about half the total number represented and 1288 species. Dr. Perkins considers, however, that the real Hawaiian fauna of beetles represents only 17 of these families; the other 26 families being foreign, and represented by only 71 species, or less than 3 species per family. The important families are: Carabidae with 204 endemic species; Staphylinidae 95; Histeridae 34; Nitidulidae 136; Elateridae 76; Anobiidae 134; Cioidae 39; Proterhinidae 136; (this family is peculiar to the Hawaiian islands and all the species are in the genus Proterhinus. One species, however, is known from Samoa, and it may be that more will eventually turn up outside of Hawaii. They are small bark and dead wood beetles related to the Aglycyderidae): Curculionidae 132 species; Cerambycidae 52; Coccinellidae with 2 or 3 doubtful species; Lucanidae with one endemic genus of 7 species, occurring only in a limited area on the high plateau of Kauai. The following important families are absent: Cicindelidae, Buprestidae, Chrysomelidae, Scarabeidae and Bruchidae. The greater number of the endemic beetles are small and obscure. The Carabids are of fair size, but usually not much met with except by searching in special places. The native Cerambycidae are the ones of greatest attraction, and are of respectable size. They are considered prizes when captured; for as there are but a few species of them on each island and as each is associated with particular trees and attacks them at a certain stage of injury, or decay, they are not often met with in ordinary collecting.

Of the Lepidoptera 764 species were listed, nearly equally divided between the Macrolepidoptera and the Microlepidoptera. Of these, 92 per cent were considered endemic. Moths predominate, there being but two native species of butterflies. One is the Kamehameha butterfly (*Vanessa tameamea*) related to the red admiral in the states. The other is one of the "blues" (*Lycaena blackburni*). Both species occur on all the islands and are usually to be seen on a day's collecting trip in the mountains. They rarely come to the sea level. Eight other species of butterflies are to be seen on the lowlands, chiefly common American or cosmopolitan species. The

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Sphingidae are worthy of mention with four native forms of Celerio which show relationship to an American species; and one species of Tinostoma whose relationship is not known, and of which but a single specimen has been secured. There are comparatively few families of the moths, the chief among them are: Caradrinidae with 34 species; Hydriomenidae 17; Selidosemidae 39; Pyraustidae 72; Gelechiidae 41; Hyponomeutidae 270; Carposinidae 33; Tortricidae 45; Tineidae 15. Of the 117 genera represented, 37 are endemic and 12 of them belong to the Hyponomeutidae. The most prominent of these genera is Hyposmocoma with 177 species, or 25 per cent of all the endemic Lepidoptera. These are small moths with great variation of color patterns, which run in groups of 6 to 10 species of great similarity. Their larvae are in cases, usually covered with bits of lichen or moss. They occur among mosses and lichens on tree trunks, ferns, rock surfaces, and in hollow twigs, dead branches, etc. This group is worthy of a great deal more study. It is likely that many more species will be found, a considerable number of those now known being described on single specimens.

Neuroptera in the broad sense has 116 species. The most important features of this group are the lacewingflies (Hemerobiidae) with 51 native species, and the damsel flies (Agrion) with 26. Two species of antlion are known. Such families as Trichoptera, Perlidae, Ephemeridae, Mantispidae and Panorpidae are entirely absent.

Diptera has 135 endemic species occurring in but 10 families; Mycetophilidae, Chironomidae, Limnobiidae, Dolichopodidae, Pipunculidae, Sarcophagidae, Anthomyidae, Trypetidae, Drosophilidae and Asteidae. Such important families as Culicidae, Tabanidae, Syrphidae, Asilidae, Muscidae, Dexiidae and Tachinidae are conspicuously absent from the endemic fauna, though in the Culicidae we have three foreign mosquitoes which are sufficient to make up for any lack of native species. The extraordinary development of the Drosophilidae is the most striking feature of the dipterous fauna, there being about 50 species known, and probably many more will yet be found. Most endemic Diptera are small and obscure, the crane flies and the Sarcophagidae being the most conspicuous in size.

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Hemiptera has 238 endemic species (which number has been considerably increased since the publication of "Fauna Hawaiiensis") divided nearly equally between the Heteroptera with 110 species and the Homoptera with 128. These figures will be greatly increased by further work in these groups. Most prominent families of the Heteroptera are Miridae, Nabidae and Myodochidae. Six other families have but a few species. In the Homoptera the important families are Delphacidae, Cixiidae, Tettigoniidae and Psyllidae. These are mostly leafhoppers and treehoppers, being largely tree inhabitants instead of living in grass or herbage, and are in the main attached to particular trees. Of late years they have received a good deal of attention and study by most of the local entomologists. The scale insects and plant-lice have many immigrant forms present in the islands, but there are a few mealybugs which appear to be native.

Orthoptera has very few endemic species. Of the 83 species known only about half are endemic. There are no stick insects or mantids except two introduced species of the latter; no true grasshoppers except two foreign ones; of the several roaches and earwigs, there is possibly one of each which is native; the Locustidae has 9 native species, and there are 35 crickets. They are mostly small crickets of the genus Paratrigonidium, but several species are very elongate and belong to an endemic family, Prognathogryllidae. They are the most interesting part of the Hawaiian Orthoptera, being flightless, with very elongate antennae, are nocturnal in habits, concealing themselves in the daytime beneath bark, in holes in decayed wood, or in hollow stems. One must be quick to capture them when they escape on being disturbed.

A peculiar feature in some orders is the presence of certain families represented by a single species, or 2 or 3 species at the most. These are considered to be of more recent arrival than those families with many species, especially those with endemic genera having many species, which would be considered as having developed from ancestors that arrived at a much more remote time.

Flightlessness is quite prominent in some of the orders. A great many of the species of Carabidae are flightless. These all have the elytra fully developed, but have only vestigial wings. A good many in the Homoptera and Heteroptera are also flight-

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less, as are a few species of parasitic Hymenoptera, Diptera, and Hemerobiidae of the Neuroptera.

Since the time of the collecting for and the publication of the "Fauna Hawaiiensis," there has been no one working exclusively on the native insect fauna, but all the entomologists of the several institutions here, working chiefly on lines of economic entomology, have been interested in advancing the knowledge of the native insect fauna. These entomologists have been associated in an organization known as the Hawaiian Entomological Society, which holds monthly meetings for the presentation of papers and the discussion of entomological subjects. This society has been in existence since 1905 with a membership of 20 to 30, including professional entomologists and others interested in the subject. The printed "Proceedings" of the Society has amounted to 1479 pages. It includes quite a number of descriptions of new species discovered and described by various members.

Much interest is taken by the local entomologists in the relation that the Hawaiian insect fauna may have to that of other Pacific island groups, when the latter have been as thoroughly studied, and comparisons can be made with them, and in the bearing that this may have on the solution of such problems as the origin of the Hawaiian insect fauna, also the flora, and the origin of the Hawaiian group itself—whether part of a submerged continent or of independent origin, discussion of which theories I will not enter into here.

A word as to favorable or accessible places for collecting the endemic insects. Near Honolulu, the most desirable places are the trails to Mt. Olympus and Mt. Konahuanui (peaks of 2500 and 3000 feet elevation respectively) in the Koolau Range about 5 miles back of the city. More remote regions accessible by trails are Waiahole, Kahana, Punaluu and Wahiawa of the Koolau Range, and Mt. Kaala (4000 feet elevation) in the Waianae Range. The best collecting is found at 2000 feet elevation and above. An immigrant ant (*Pheidole megacephala*) has played havoc with the native insect fauna of the lower regions, and one must get well above its line of advance. It is probable that some of the endemic species have been exterminated by this ant.

On Kauai, the region above the Waimea Canyon and the high plateau is penetrated by numerous trails. On Maui, the best collecting is on the upper slopes of Haleakala, an extinct volcano of 10,000 feet elevation; also the lower part of the wind-

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ward forest which is penetrated with great irrigation ditches. The most favorable collecting place of all is on Hawaii in the region of the actve volcano, Kilauea, at an elevation of 4000 feet. Here within easy distance are varying conditions from extreme desert, to very rainy fern forests. More collecting has been done here than at any other one place in the islands, with the possible exception of the immediate vicinity of Honolulu.

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SOME ASPECTS OF ECONOMIC ENTOMOLOGY IN HAWAII

By D. T. Fullaway

It is customary in dealing with Hawaiian insects to distinguish between endemic and non-endemic forms, but there is really no hard and fast line between the two; it often becomes difficult to decide whether an insect in hand should be included in one category or the other, and the worker's judgment is taxed to reach a satisfactory conclusion. It appears to me that a more proper distinction would be between early and late immigrants; but our knowledge of immigrants except in a casual way goes back only a very short time, and other criteria than collectors' records are generally used to determine the insect's status with regard to endemicity. It is patent, however, on very limited acquaintance with the fauna, that the endemic insects, or those so-called, play a very small part in the economic life of the country; that the insects of economic importance are almost entirely late immigrants, insects that have appeared on the scene while the agricultural and related industries of the country were being built up. As this development progressed, the endemic insects, dependent for the most part on the endemic vegetation, have receded with it to the more inaccessible places, and the field they have vacated the immigrants have occupied.

A business man in Honolulu was once heard to remark apropos of the advent of some new insect pest "Yes, and all that haven't got here yet are on the way." This was meant to be facetious but it states an actual fact and one of great importance to us. If the insects we have to deal with are practically all immigrants and more are coming all the time, it would appear that our most important and most pressing problem is to find the means to ward them off.

If we had not the great barrier of ocean which surrounds us it might be important to study the means of insect migration more than we have done and develop counter measures; but while some species present here can be accounted for by supposing they have used the natural means of transportation such as flight, drift, etc., it is almost certain that the bulk of our economic species have come on the ships which enter our ports in the pursuit of commerce, and to prevent the entrance of these invaders we have our horticultural quarantine. It seems to me,

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however, we do not generally realize the commanding importance of this work,—our first line of defence against insect pests. The prosperity of the country demands that it should be tightened to the fullest extent possible by prohibitions, closer inspection and, if necessary, the maintenance of quarantine grounds for plants. The trend of the practice today is in this direction and has every reason behind it when it is considered to what an extent shipping has increased here, how much greater use is being made of our wharves, the development of new lines of travel since the war, etc., etc. It seems to me also that money might be profitably spent investigating the insect pests of the lands whence most of our travel comes for the purpose of preparing a defense in anticipation of their invasion.

I am particularly insistent upon this point in view of our experience with insects that have been anticipated and have eventually gained access to the islands. Their behavior is such that ordinary measures of repression and control are usually fruitless. The reasons for this can be stated in a way. A highly favorable climate and the absence of the usual restraints permit almost continuous breeding which results in an excessive multiplication of individuals. A rapid dissemination follows which can not be checked before the pest has occupied uncultivated, rocky, mountainous or otherwise inaccessible areas. The failure of artificial methods of insect control to give results here, and their general unpopularity I attribute mainly to this peculiar behavior of our immigrant insect fauna. Methods requiring incessant application of expensive measures and failing to give desired results are almost certain to be unpopular. There is no doubt that the great dependence placed on natural control of insect pests in these islands has come about through the success of this method and failure of artificial methods. Experience has shown that it is the method adapted to our needs and to our conditions. This method involves the searching out and introduction of the parasites and predators on our destructive immigrant species in the lands from which they have come. Parasitism and predation among insects is a very common phenomenon which even the layman today is acquainted with and the check which this parasitism exerts on the multiplication of insects is also well known. It should be pointed out here that the same circumstances which prevent the migration of injurious insects to our isolated islands also prevent beneficial insects from reach-

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ing us. Likewise the same causes which lead to the rapid spread and excessive multiplication of injurious introductions operate equally on the beneficial ones that prey upon them. The absence of severe competition which immigrants enjoy is also balanced by the freedom from the possibility of hyperparasitism. If the application of this method to the subjugation of an insect pest does not result in a full and complete control of the pest it at least brings its multiplication within such bounds that artificial methods can be used with some degree of satisfaction. The main defect of the method from a practical standpoint is its limited application.

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WHAT HORTICULTURAL PLANT QUARANTINE HAS DONE AND CAN DO FOR HAWAII

BY EDWARD M. EHRHORN

In the early eighties of the 19th century the State of California accomplished a great work—the establishment of a Horticultural Plant Quarantine. At that time the fruit industry of California was growing in bounds and two serious pests, the San Jose scale and the Fluted or Cottony Cushion scale appeared in such enormous numbers as to threaten the deciduous fruit as well as the citrus industry. Both of these insects were of foreign origin. The Commissioners of Horticulture and the fruit growers realized then that to prevent other similar pests from being introduced on foreign plant shipments something must be done and done quickly. Stringent laws were therefore enacted which made possible the control and supervision of all horticultural importations. And it was well that California did pass these laws for the records of the Horticultural Board show that many dangerous pests were found on shipments of plants from all parts of the world which would no doubt have become established in the State but for their strict examination and destruction at the port of entry.

Since 1904 the Territory of Hawaii has followed the good example of its coast neighbor and through stringent laws has prevented many dangerous insect pests and plant diseases from gaining a foothold in these islands.

Most of the injurious insect pests now found in Hawaii affecting the various field and garden crops and other plants as well as stored products are of foreign origin. Barring a few cosmopolitan species, these pests have been introduced from countries surrounding or situated in the Pacific Ocean. The same may be said of the mainland of the United States; there, however, we also find pests from countries bordering on the Atlantic Ocean.

The Commissioners of Agriculture and Forestry in Hawaii, fully realizing the importance of absolute control and knowing of the existence of dangerous pests such as fruit flies and cane insects prohibited the importation of all fruits and sugar cane from the East or West Indies, Asia, Australasia, Oceanica, Malaysia, Mexico, Central and South America.

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When we consider the enormous army of destructive pests scattered all through the lands of the Pacific Ocean only waiting a chance to gain admission here, Hawaii may well be considered fortunate in having so few insect pests attacking its most important crop—sugar cane. From a record of the United States Department of Agriculture "A Manual of Dangerous Insects Likely to be Introduced in the United States Through Importations" we find that sugar cane insects alone not at present known here in these islands run into hundreds of species. Of the well-known pests, there are 10 species recorded from Java, India, Formosa, and adjacent territory, represented by Red Spiders, Froghoppers, Tenebrionids, Scarabeids, Buprestids, Chrysomelids, Pyralids, and Tortricids. Among other important sugar cane pests of record, not thoroughly studied as to their spread, habits and destructiveness, we find 50 pests belonging to the Lepidoptera, 25 to Coleoptera, 50 to Jassids and Fulgorids, 21 to Coccidae, 21 other Homoptera, 27 Locustidae and 7 Gryllidae.

Our second important product—the pineapple—is attacked by only two scale insects which might be considered troublesome, especially if clean culture methods are overlooked. This is indeed very fortunate if we glance over the long list of pests that remain outside of our country. In the Pacific lands there are a number of serious pests of the pineapple among which a fruit fly, *Dacus xanthodes* of Fiji would prove very destructive if it were ever introduced.

I could go on indefinitely, taking up the citrus, mango, avocado, coconut, fig, forest trees generally, garden crops and forage crops, and from records at hand show that each one has many injurious pests which have not gained entry here.

We are again fortunate since the quarantine rules of the Federal Horticultural Board of the United States Department of Agriculture have been enforced, for under these regulations very few plants can be imported into the United States and its territories.

Since the organization of the Federal Horticultural Board much time and study has been devoted to acquire better knowledge of the dangerous pests of agriculture in the countries where these pests are known to exist and it has been possible at first hand to study and report their bearing on the future success of plant quarantine. In Hawaii the Board of Agriculture and Forestry and the Hawaiian Sugar Planters' Association have sent

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entomologists and plant pathologists to the various countries in the Pacific in search of enemies of our most destructive pests, and these men have not only accomplished that which they sought to accomplish, but have had a great opportunity to study a few of those pests which it is absolutely necessary to keep out of Hawaii. However, we need more such work; we have just touched the border. The more we know about the pests injurious to our crops the better off we shall be, and we should continue research on this problem and should endeavor to establish the most cordial coöperation with our fellow-workers of the countries of the Pacific.

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MISCELLANEOUS PAPERS ON BOTANY

CULTIVATED PLANTS OF POLYNESIA AND THEIR VERNACULAR NAMES, AN INDEX TO THE ORIGIN AND MIGRATION OF THE POLYNESIANS

By William E. Safford

Erroneous theories relating to the physical geography of the Pacific Ocean and the origin of the Polynesians have been perpetuated by recent popular writers. Some of these assert that the Pacific islands are the vestiges of an ancient continent which sank beneath the waves leaving only the peaks of the highest mountains above the surface. The natives of these islands have been divided into several ethnological groups, one of which, the true Polynesians, includes the Hawaiians, the Maoris of New Zealand, the Samoans, Tongans, Rarotongans, Marquesans, and Easter Islanders, the last named inhabitating a small volcanic islet at the southeast extremity of Polynesia, situated in longitude east of the meridian of Salt Lake City. Among the absurd theories above referred to is one which holds that the Polynesians are of Caucasian origin; another hints that Easter Island was formerly inhabited by some mysterious race distinct from the Polynesians and suggests a Melanesian strain in the natives; while one writer asserts a connection between the inhabitants of the Peruvian Andes and the authors of the curious inscribed wooden tablets found on the islands, which he pretends to decipher.

In attempting to trace the origin of the Polynesians one of the most certain guides is the study of their economic plants together with the vernacular names applied to them in the various island groups. Some of these plants are important food staples; others are used for making intoxicating drinks; others for cordage or textile purposes or as a source of dyes or pigments. The range of some species is restricted to the more tropical islands while others occur throughout Polynesia. I shall first speak of the species which have found their way across Polynesia to Easter Island, which from an ethnological point of view is perhaps the most interesting island of the Pacific Ocean. Among the plants introduced into this island in prehistoric times, are a number whose vernacular names

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are identical with the same or similar species in Hawaii. Many of them may be traced to the Malay Archipelago, the cradle of the Polynesian race. Following is a list of the most important economic plants of the Easter Islanders together with their botanical names: *taro* (*Colocasia antiquorum*), called *kalo* by the Hawaiians, in whose language the *t* of southern Polynesia becomes *k*, the *r* becomes *l*, and the primitive *k* is indicated only by a break between vowels; *kape*, or *kapi* (*Alocasia indica*), the giant acrid taro called *'ape*, or *'api*, by the Hawaiians; *toa* (*Saccharum officinarum*), sugar cane, called *ko* by the Hawaiians; *meika* (*Musa paradisiaca*), the banana, called *mai'a* by the Hawaiians; *ti* (*Cordyline terminalis*), the well-known *ki* of the Hawaiians, who make from its root an intoxicating drink; *hara* (*Pandanus tectorius*), the *hala* or *lauhala* of the Hawaiians; *pia* (*Tacca pinnatifida*), the Polynesian arrowroot, which is called by the same name in Hawaii; *uhi* (*Dioscorea alata*), a yam whose vernacular name is identical with the Samoan *ufi*, the New Zealand *uwi*, the Madagascan *obi* and the Malayan *ubi*, applied to the same and kindred species, as well as with the Hawaiian *uhi* which is applied to the yam-like root of a species of Smilax; *hue* (*Cucurbita lagenaria*) a gourd, the fruit of which, called *ipu*, is utilized for water-bottles or food-containers, also called *hue* and *ipu* by the Hawaiians; *maute* (*Broussonetia papyrifera*), the paper mulberry of which the Polynesians make their tapa cloth, called *aute* by the Tahitians and New Zealanders and *wauke*, or *oauke* by the Hawaiians. The very name applied to Easter Island itself, *Te Pito o te Henua*, is etymologically identical with the Hawaiian *Ka Piko o ka Honua;* and just as in Hawaii land is called *honua* or *'aina*, so in Easter Island it is *henua* or *kainga;* the Hawaiian *uka* and *kai* in *mauka* (landward) and makai (seaward) are identical with the Easter Island *uta* and *tai*. The Hawaiian *'a'ole* (no) becomes *kakore;* and *lani* (heaven) becomes *rangi;* *aloha* (love) becomes *aroha* and *'oe* (you) becomes *koe*.

I ask indulgence for this digression. I could not refrain from pointing out the relationship between the Easter Islanders and the Hawaiians. The very close resemblance between their languages is remarkable in view of the enormous distance which separates them. I could go farther, in presenting to you their remarkably parallel calendars or systems of dividing the lunar month, the identity of their divinities,

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their systems of taboo, etc., but I will refrain. I must, however, say here that there is no indication either on Easter Island or in Hawaii that the present inhabitants were preceded by people of a race distinct from the Polynesians. Easter Island is so far removed from the equator that certain staples of the more tropical islands of the Pacific will not grow there. The most important of these are the coconut and the breadfruit, both of which are Asiatic plants which accompanied the Polynesians in their migrations, and have been established in all climates which will permit them to live. Another important Polynesian plant conspicuous for its absence in Easter Island and New Zealand is the narcotic *kava* or *'awa* (*Piper methysticum*), the roots of which are used for preparing an intoxicating drink.

The coconut (*Cocos nucifera*) now so widely spread in the tropics, is called *niu* throughout Polynesia, a name easily identified with *niug* or *nivog* of Guam and the Philippine Islands, and with *nior* or *niyor* of certain islands of the Malay Archipelago. Precolumbian writers, including Marco Polo, referred to this fruit as the *nux indica* and called attention to it as an important source of oil. There is no evidence that it reached America before the Discovery. Its buoyant husks render its transportation by ocean currents possible yet in most cases it has undoubtedly been spread through human agency.

Bananas and the seedless breadfruit were carried from island to island in the form of sprouts or suckers, and sugarcane in cuttings. The identity of the Hawaiian names of these plants with those of southern Polynesia is most significant. They are all found in Guam and the Philippines, and must have come from the Malay Archipelago. On the other hand the paper-mulberry is probably of Japanese origin: the tapa made from its inner bark is in reality a coarse paper. The *ti* plant and the *'awa*, or *kava* pepper, were in all probability encountered by the Polynesians after they had entered the Pacific. The Maoris of New Zealand have certain legends conected with the *ti*.

Several of the most conspicuous trees of Hawaii now growing spontaneously were undoubtedly introduced in prehistoric times. Among them are the *kukui*, or candle-nut (*Aleurites moluccana*) which covers the mountains back of Honolulu like pale green tapestry; the *kou* (*Cordia subcordata*)

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from which the ancient Hawaiians made some of their most beautiful poi-containers; the *ohia* (*Eugenia malaccensis*), the fruit of which is edible; the milo (*Thespesia populnea*), also the source of a beautiful wood from which "calabashes" were formerly made; the *kamani*, or *kamanu* (*Calophyllum inophyllum*), which yields an aromatic gum; and the *hau* (*Hibiscus tiliaceus*), the source of an important bast fibre. All of these trees occur in Asia, some of them are now of world-wide distribution. The origin of the kukui is indicated by its specific name *moluccana*. The name "kukui" is derived from the fact that its oily nuts are "*kukuied*," or strung together, to form candles; in Samoa it is called the *lama*, or torch tree. The Hawaiian name *kou* is identical with the Samoan *tou*, applied to the same species of Cordia; the name *milo* is widely spread; in Easter Island it is applied to a leguminous shrub in the form of *toro-miro;* and similarly *hau*, the name of *Hibiscus tiliaceus* is applied to a distinct species of the mallow family from the bark of which a textile fibre is prepared. The variations in this name are most interesting; in Samoa it becomes *fau*, and is applied also to certain Urticaceous plants yielding fibre; in Guam it becomes *pago;* and in the Philippines *bago*, or *balibago*. The handsome glossy-leaved *kamanu*, called *tamanu* in southern Polynesia, is identified with the "Alexandrine laurel" of India.

From the evidence here offered it is certain that the principal economic plants of the Polynesians are from Asia, whence they accompanied the Polynesians on their migrations. Corroborating this evidence by that of comparative philology, which shows that nearly all the primitive words, or names of natural objects in the Polynesian dialects can be traced to the Malayan archipelago, we can share with confidence the belief of the Rev. George Pratt, who devoted forty years to the study of the Polynesians and their language. According to this distinguished scholar the Polynesians must have migrated before the primitive Malay language had become corrupted by the inundation of the Arabic and by the introduction of Sanscrit words from India. Just as the Arabic became softened by Malay influence so, he suggests, the Malay language may have been hardened by Arabic influence, changing such words as the primitive *langi* (sky) to the modern Malayan *langit;* ika (fish) to *ikan; ua* (rain) to *ujan; ala* (road), to

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jalan; afi (fire) to *api*. Whether or not the Polynesian dialects were derived from the Proto-Malayan, it is quite certain that these languages had a common origin, and it is very probable that the ancestors of the Polynesians were closely related to those of the brown people now inhabiting the Moluccas and Celebes, whom they resemble in both physical appearance and in language.

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NEW ZEALAND'S CALL TO THE BOTANIST

By Charles Chilton

New Zealand lies in the South Pacific Ocean, separated from Australia by the deep Tasman Sea about 1200 miles wide. The two large islands, north and south, extend from about lat. 35°S to 46°6'S, the main axis of land being about 1000 miles in length.

In addition to the two large islands, and those that are immediately adjacent to them, there are numerous other outlying islands included in the biogeographical region of New Zealand as defined by Hutton in the Index Faunae Novae-Zealandiae. These include the Kermadec Islands to the north, the Chatham Islands to the east and the Antipodes, Bounty, Lord Auckland and Campbell Islands to the southeast. Macquarie Island still further south is included in the area defined by Hutton and is certainly more nearly related biologically to New Zealand than to any other large area of land, though its fauna and flora have a decidedly Antarctic aspect; and politically it is under the control of Tasmania. The Cook Islands and the Samoan Islands that previously belonged to Germany are now under the jurisdiction of New Zealand and their possession emphasizes New Zealand's connection with the Pacific and with the scientific problems connected with that ocean.

The coast line of New Zealand is greatly indented and irregular and in consequence is of great length compared with the enclosed land area. Within comparatively short distances it shows great variety of rocky cliffs, sandy beaches, wooded shores, tidal bays and mud flats. The land surface extends from sea level to mountains reaching to a height of 12,000 feet and includes extensive plains, some presenting features of deserts, others rich well-watered lands, swamps, rivers and large fresh water lakes. Consequently the vegetation varies exceedingly and shows greater diversity than can be met with in any other portion of the globe of similar area. Much of the surface and of its vegetation has been greatly altered by civilization and cultivation, but on the mountains and in the great valleys, especially on the west coast of the South Island, the native forest remains almost untouched and the indigenous flora unchanged and never likely to be entirely destroyed.

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Outlying islands near the coast have been set aside as animal and plant sanctuaries. They have been separately selected so as to be suitable for as many different kinds of animals and plants as possible. These sanctuaries are Little Barrier Island, off the coast of Auckland, Kapiti Island near Cook Strait, and Resolution Island off the southwest of Otago. In addition to these there are large national parks around some of the mountains and along the courses of some of the rivers, where an attempt is also being made to preserve the indigenous flora. The rainfall as a whole is abundant, but shows great variety in different parts. For example in the Canterbury Plains near Christchurch it is about 25 inches per annum only, while at Otira, on the western slopes of the Southern Alps, only 80 miles away in a direct line, it may be 190 inches. So varied are the conditions for plant growth that Dr. Cockayne in endeavoring to divide the area botanically had to establish no less than fifteen botanical regions.

The flowering plants and ferns have already been pretty carefully surveyed and dealt with from a systematic point of view, and most of the species are probably already known, though some additional ones doubtless remain to be discovered and the relationships of those already named require much further investigation. In the lower plants, like the algae and fungi, the field is much more unexplored. The relationship of the New Zealand plants to those on the islands to the south of New Zealand and on other subantarctic islands has been dealt with somewhat fully by various investigators, but it will be necessary to know much more accurately their distribution on these islands and their affinity to the former plant covering of the Antarctic Continent, before final conclusions can be arrived at. Similarly as regards the plants that may be supposed to have reached New Zealand from the north a wide field of inquiry lies open and the relationship of the New Zealand species to those on Lord Howe Island, Norfolk Island, New Caledonia and New Guinea offer a fruitful field for further investigation. Particularly would a careful comparison of the special features of the New Zealand flora with those of the Hawaiian islands, which, like New Zealand, have long been separated from any large area of land, be likely to afford interesting and valuable results as to the method by which such isolated areas have become covered with plants.

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A good foundation for a knowledge of the ecology of New Zealand plants has already been laid by several writers, but the clothing of the shingle slips, river beds and shingle fans in the subalpine regions and denuded areas in the volcanic regions presents botanical problems that can perhaps be studied with greater economy of effort and labor in New Zealand than in any other country. The Canterbury College Mountain Biological Station at Cass, situated at a height of 2000 feet above sea level, offers special facilities for work on some of these problems.

Many interesting results may be expected from a careful examination of the species that have been introduced and of the reasons that have enabled some to spread widely while others remain restricted in area. The contest between the introduced species and those indigenous to New Zealand should give opportunities for observations and conclusions likely to be of wide application in questions concerning the distribution of plants. The wide extent of country and the varied character of the climate permits of the production of many plants of economic value, but as yet very little has been done in the way of experiment to ascertain what products could be profitably grown between the wheat, oats and other crops of the agricultural farm.

Particularly is it necessary without delay to ascertain whether the native forests of New Zealand can be treated so as to yield a continuous supply of timber and how far it will be necessary to supplement them by the introduction of timber trees from other countries.

Past experience elsewhere has conclusively shown that these problems can be profitably solved only by acquiring a wide and sound scientific knowledge of the plants dealt with and of the conditions under which they grow, though investigations of the kind may apear at the time to have no bearing on economic problems.

The following list contains a few of the chief works dealing with New Zealand botany. From them references to others can be readily obtained.

Transactions of New Zealand Institute, vols. 1 to 52, 1868-1920.
Hooker, J. D., Flora Novae Zealandiae, 1853-55.
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Cheeseman, E., Manual of New Zealand Flora, 1906.
Laing and Blackwell, Plants of New Zealand, 1906.
Subantarctic Islands of New Zealand, vols. 1 and 2, with bibliography, 1919.
Cockayne, L., New Zealand Plants and Their Story (new edition), 1919.

COMMENT BY MR. SAFFORD

New Zealand's call to the botanist is indeed alluring not only to the systematist and the student of phytogeography but to all those interested in the origin and uses of cultivated plants. During our recent excursions in the mountains of this island, the members of the Section of Botany have been impressed by the comments made by New Zealand delegates on certain similarities between the flora of Hawaii and that of New Zealand, in some cases the similarity extending to the vernacular names of plants of the same genus or plants more or less resembling each other. Thus on encountering the climbing screw-pine (*Freycinetia arnotti*) and hearing its local name *ieie*, they would exclaim: "Why, we too have a Freycinetia and we call it *kiekie!*" On seeing the natives gathering the fragrant myrtle-like *maile* (Alyxia) for making *leis*, or garlands, they recognized its name as being identical with their own *maire*, which in New Zealand is applied to certain plants with glossy myrtle-like leaves. In the same way the name awa, applied to the narcotic *Piper methysticum* by the Hawaiians, becomes kawa-kawa in New Zealand, where it is used to designate an allied plant, *Piper excelsum*. This, though not narcotic, is pleasantly aromatic and stimulating and is used as an anodyne for toothache. The name *ti*, applied to *Cordyline terminalis* is in New Zealand used for many species of the same genus, including this one, so dearly beloved by the Hawaiians. In ancient times it was an important food plant of the Maoris, and may still be found in their abandoned plantations. Another food plant used by both the Maoris and the Hawaiians and bearing the same name is *taro*, the starchy root of which is here the source of poi. The large gourd, *Cucurbita lagenaria*, is called *hue* in both New Zealand and Hawaii, and the food receptacles and drinking cups made from its shells are called *ipu*. *Uhi*, the name for yam (N. Z. *uwhi*) is applied to the potato and to the edible starchy root-stock of a fern (*Marattia fraxinea*). The genus Pandanus does not occur in New Zealand, but the Maori name *whara*, applied to floor-mats, is easily identified with the Hawaiian *hala* and the Samoan *fala*, from which mats are braided. The *hau (Hibiscus tiliaceus)* and the *milo (Thespesia populnea)* are also absent from New Zealand, but their names in the form of *whau* and *miro*, are applied by the Maoris to other plants resembling them either in the form of their leaves or in the texture of their wood. The paper-mulberry, called *wauke* by the Hawaiians and *aute* by the Maoris, was used by their common ancestors as a source of bark for tapa-making. This plant is no longer used in New Zealand, and is there almost extinct. All of these plants originated in the Eastern Hemisphere; but *Hibiscus tiliaceus*, an important source of cordage and *Cucurbita lagenaria* furnishing "calabashes" to primitive people, had found their way to America in precolumbian times. The only American plant of economic importance which reached the Polynesians before the days of Captain Cook was the sweet-potato, called *kumara* in New Zealand and *uala* in Hawaii. It is interesting to note that taro, ti, and the paper-mulberry were also cultivated by the Easter Islanders who called them by the same vernacular names; and the natives of the last-named island, *Te Pito o te Henua* (*Ka Piko o ka Honua*), also cultivated the sweet-potato and called it *kumara*. It is quite probable that this species first

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established itself in the Pacific on certain islands of southwestern Polynesia. We know that it had not reached Guam nor the Philippines before the voyage of Magellan. To both the Mariannes and the Philippines the sweet-potato was brought by the Spaniards from Mexico with its Aztec name *camotl*, or *camote*.

Apart from the botanical interest which the cultivated plants of New Zealand and the various island groups of Polynesia may have, their vernacular names demonstrate, in a most striking manner, the homogeneity of the Polynesians and point to Malaysia as the cradle of their race.

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THE FIELD LABEL IN BOTANY

By Elmer D. Merrill

If we critically examine any herbarium we invariably find that the herbarium sheets present almost no data other than those currently recorded, the scientific name, collector, locality, and data of collection. Special notes, local names, economic uses, etc., are either not recorded by collectors or if recorded are contained in notebooks and as a general rule such data is not transferred to the herbarium sheets. As a result most herbaria are not fulfilling their proper functions and are almost never consulted by other than systematic botanists on account of the dearth of data other than that valuable to systematists.

Current methods of field work and current methods of recording data regarding individual collections must be modified if the large older herbaria and the new herbaria now being built up are to be made more generally useful. It is believed that this end can be gained by adopting a simple method of field labels on which economic data may be recorded in the field, these field labels to be attached to the mounted sheets so that all the original data are at once available to those consulting the collections. This method has been developed in the Philippines with the most admirable results so that the large herbarium of the Bureau of Science is now not only an index to the systematic aspects of the Philippine flora but also to the economic aspects as well. The collections are consulted not only by systematic botanists but also by foresters, individuals interested in economic botany, philologists, and others because the data such individuals desire are all available in the herbarium.

The field label idea has been developed not only for the use of the trained collector, but also with a view to the needs of the untrained individual, indicating in a simple manner the data that should be recorded with each individual collection. Through its use it has been possible to assemble a vast amount of economic data, such data as is in general not available in the herbaria of the classical type. The form given herewith (fig. 1) is that adopted for the current botanical work of the Bureau of Science and may be modified to meet the local needs or for any specific purpose. The original label is placed with the specimen when it is arranged in the press for drying, remains with the specimen during all stages of preparation, and is finally attached to the upper left hand corner of the mounted herbarium sheet.

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FLORA OF THE PHILIPPINE ISLANDS.
HERBARIUM, BUREAU OF SCIENCE.

Common name .... ***Dialect*** ....

Field No. .... ***Herbarium No.*** ....

Collector..

Island or Province ....

Locality ....

Habitat...

....

Altitude above the sea .... ***meters.***

Tree; shrub; bush; vine; herb...........................

Height of plant .... ***M.***

Diameter, breast high .... ***Cm.***

Flower ....
(Odor, color, etc.)

....

Fruit ....
(Kind, odor, color, etc.)

Special notes ....

....

Economic uses ....

....

2—569

Date ....

FIGURE 1. Field label used in the herbarium of the Philippine Bureau of Science. Reproduced full size.

Through its use it has been possible for the Philippine Bureau of Science to utilize the services of scores of individuals, often untrained natives, both in and out of the government serv-

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ice, in compiling valuable economic and ethno-botanic data. Forms have been freely distributed to amateur botanists, foresters, rangers, missionaries, teachers, ethnologists, geologists and others, and the results obtained have really been marvelous. By supplying small collecting outfits and field labels we have been able to secure from non-botanical expeditions very extensive and valuable collections which otherwise would not have been made, not because the non-botanical individuals were not interested in securing botanical material but because they had no knowledge of how to prepare specimens, a very simple process, or how to record notes.

This brief paper is presented chiefly for emphasizing the great value and eminent utility of field labels in current field work in botany and to impress on the members of non-botanical expeditions the great desirability of their coöperation in collecting botanical material in the more isolated and little-known parts of the world. With very slight additional equipment any expedition into Polynesia will be in a position to secure exceedingly valuable botanical material and with the use of simple field labels record the data desirable from the standpoint not only of systematic botanists but also the biologists, the entomologists, the philologists, the foresters interested in purely economic phases of botany.

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SOME RECENT INVESTIGATIONS ON THE FLORA AND PHYTOGEOGRAPHY OF JAPAN AND ADJOINING REGIONS

By K. Shibata

The following paper is not offered as a thesis, but is intended to present a brief survey of recent phyto-geographical and floristic works by Japanese botanists together with a discussion of their salient features bearing upon problems connected with Pacific regions.

As is well known, Japan is a very much extended country in latitude as well as in altitude, and has consequently a wide range of variation in climatic, soil, and other conditions. The extraordinary richness in plant life thus brought about has long been the .object of eager studies by many foreign and home botanists, among whom might be mentioned in this place Kaempfer, Thumberg, Miquel, Siebold, Maximowicz, Frantiet, Yatabe, Matsumura, Miyabe, Makino and others. The decided progress in the floristic exploration of our land made in these decades is borne out by the fact that Matsumura was able to enumerate more than 7000 species of vascular plants, belonging to 194 families, in his "Japanese Names of Plants," published a few years ago. Though our knowledge of lower forms of plants occurring in Japan is far from complete, we may still add to the above numbers some one thousand species of marine and fresh water algae (excluding diatoms) and three thousand five hundred species of fungi and bacteria. Thus the total number of plant-forms hitherto known from Japan considerably exceeds 10,000.

As the floristic investigations of our territories, Korea and Formosa, have been pursued in recent years with remarkable success, an up-to-date statistical representation of results attained might be of some interest. At my request, Dr. T. Nakai, the government botanist of Korea, has summarized his studies in the following table. (The figures in parentheses indicate the number of endemic forms):

	Number of			
	Fam.	Gn.	Sp.	Var.
Pteridophytes	12	42	206 (17)	15 (4)
Gymnosperms	2	10	21 (4)	
Monocotyledones	20	175 (1)	633 (62)	100 (45)
Archichlamydeae	82	373 (3)	1301 (218)	240 (100)
Metachlamydeae	35	214 (2)	698 (127)	81 (147)
Total	151	814 (6)	2859 (428)	436 (296)

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Previous to the work done by Nakai, some 1400 species belonging to 130 families and 550 genera were known from Korea through the investigations of Palibin, Komarow and others. The most noteworthy plant found by Nakai is *Hanabusaya asiatica nov. gen. et nov. sp.*, a perennial herb with beautiful blue-violet flower, belonging to the family Campanulaceae. Among the arboreous elements, composing one-fourth of Korean flora, a new salicaceous genus, Chosenia (Chosen being the Japanese designation of Korea) was made known by the same author, quite recently.

Concerning the Formosan flora, a statement similar to the above can be made. In 1896 A. Henry enumerated about 1400 species in his "List of Plants from Formosa." Since the acquisition of the island, in 1897, Japanese botanists began to pay attention to the flora of Formosa and made several collecting trips thereto. In 1904 Dr. B. Hayata started, under the government's auspices, a vigorous botanical survey of the island, assisted by many able collectors. He publishes results of his investigations, since 1911, in annual volumes entitled "Icones Plantarum Formosanarum" and with the ninth volume of this work, just issued, the number of flowering plants and vascular cryptogams can be summed up as follows: 169 families, 1185 genera and 3608 species, among which some 1200 are new to science. Some of the families containing the largest numbers of species are:

Polypodiaceae	442	species	belonging	to 50	genera
Gramineae	213	"	"	" 79	"
Leguminosae	184	"	"	" 62	"
Compositae	143	"	"	" 57	"
Cyperaceae	126	"	"	" 20	"
Urticaceae	108	"	"	" 30	"
Euphorbiaceae	86	"	"	" 31	"

The most remarkable plant found by Hayata is a new coniferous tree, named *Taiwania cryptomerioides*, which grows in the Middle Formosa mountain range at an altitude above 7000 meters, and attains great dimensions, exceeding not rarely a height of 30 meters and a diameter of 2 to 3 meters. Other interesting new genera are: Arisanorchis, Parasitipomoea, Polliniopsis, Dolichovigna, Pseudosmilax. The discovery of a new species of Archangiopteris, an old marattiaceous fern, and also of Mitrastemon, a curious parasite belonging to Rafflesiaceae, deserves special mention.

The phytogeographic studies, or the determinations of floral regions, along with the pursuit of their inter-relationship, involve

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a more vexed problem than mere enumeration of existing plant-forms. The distribution of plants in certain regions is influenced not only by climatic but also by historic factors. Taking all the available data in account, we may divide Japan in four floral regions, namely:

1. Arctic Region, consisting of Sakhalin, Kurile Islands and northern half of Hokkaido (excepting certain coastal districts).
2. Temperate Region, extending from south of the above toward Northern Honshu to about 38 degrees N. L.
3. Subtropical Region, comprising the part of Honshu lying south of 35 degrees N. L., Shikoku, Kiushiu and southern islands reaching to Okinawa. The middle part of Honshiu lying between 35 degrees and 38 degrees N. L. is of an intermediate character, being either temperate or sub-tropical according to the distance from sea-coast and to the elevation.
4. Tropical Region, consisting of the lowland of Formosa with adjoining islands and Bonin Islands.

The above mentioned regions are most conveniently characterized by arboreous elements, of which there are estimated to be about 600 species in Formosa and 740 in Japan proper.

1. In the Arctic Region are found *Picea ajanensis, P. Glehni, Abies veitchii, Abies sachalinensis, A. mariesii, Pinus pumila* and *Larix dahuricatin saghalien,* together with deciduous trees, such as Salix-, Betula-, Alnus-species and small shrubs belonging to such genera as Vaccinium, Ledum, Phyllodoce. The herbs belonging to Senecio, Cacalia, Petasites, Angelica, and other genera which show often a vigorous vegetative growth, are also characteristic of this region.

2. In the Temperate Region deciduous trees such as Fagus, Quercus, Ulmus, Juglans, Salix, Populus, Prunus, Acer, Fraxinus, and the conifers, Pseudutsuga, Thujopsis, Thuja, Chamaecyparis and Crytomeria are common.

3. The Subtropic Region is characterized by conifers, Podocarpus and Pinus Thunbergii, and by many evergreen trees, belonging to Quercus, Pasania, Cinnamomum, Ilex, Eurya, Sym-

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plocos, Camellia, Evonymus, Pittosporum, and other genera. Many plants, for example, *Abies firma*, *Tsuga sieboldi*, *Pinus* densiflora, Carpinus, Zelkowa and Cornus are found in both regions, forming somewhat transition elements.

4. The south end of Formosa, reaching to about 22 degrees north latitude. A really tropical vegetation thrives in this region, having several Ficus-species, *Bischoffia japonica*, *Calophyllum inophyllum*, *Garcinia multiflora*, *Terminalia catappa*, Eugenia-, Palaquium-, Hibiscus-, Acacia- species, palms, mangroves and many others as representatives. Bananas, pineapple, sugar canes, coffee, rubber trees, teak and other useful plants can be grown. The small islets of the Bonin group, showing tropical features in their vegetation, seem to contain several endemic plants, which deserve careful study from the modern point of view of the evolution of plants. The ethnologically interesting island Botel-tobago, lying east of the south end of Formosa, was botanically explored by Kawakami and others and some 430 species of flowering plants and 70 species of fern-allies are recorded from there.

As to the vertical distribution of vascular plants, distinction of zones analogous to the above stated horizontal regions can be made. At Mt. Morrison, Middle Formosa, the subtropic forest-zone lies between 500-1800 M. altitude, and consists of evergreen trees of such genera as Cinnamomum, Quercus, Castanopsis, Machilus, Trochodendron. The zone higher up to 3000 M. is occupied by the temperate forest, which contains luxuriantly growing conifers, such as *Chamaecyparis formosensis*, *Picea morrisonicola*, *Tsuga formosana*, intermingled with Fagus, Juglans, and other genera. The area above the 3000 M. limit belongs to the so-called sub-arctic zone with *Abies kawakamii* as the characteristic element. In Shikoku and Honshiu subarctic coniferous trees, such as *Abies veitchii* and *A. Mariesii* grow at an altitude above 2000-1000 M.

The distribution of bamboo plants in different floral regions is of special interest. The large bamboos, Dendrocalamus and Bambusa, are found in the tropical region of Formosa, whereas Phyllostachys- and Arundinaria-species thrive in the subtropical region. Many species of smaller bamboo plants belonging to the endemic genus Sasa grow luxuriantly in the temperate region of northern Japan, contributing greatly to the characteristic physiognomy of mountain vegetation.

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The floristic elements of Korea taken as a whole are most akin, according to Nakai, to that of Japan proper, more than seventy per cent of the former being common to both lands. The distribution of arboreous flora, especially of *Pinus koraiensis*, *Pinus pumila*, and the like, indicates clearly once existing land connection between the continent and Japan, the part of Korea lying north of 39 degrees north latitude, forming a floral district together with montane Manchuria and Ussurie, whereas the vegetation of southern Korea has a more pronounced Japanese character.

As to the comparatively recent formation of the Japan Sea evidence can also be brought forward from the distribution of marine algae. Among 17 endemic genera of sea-weeds in Japanese waters, one and only one monotypic genus *(Coccophora langsdorfii)* is, according to K. Okamura, restricted in its distribution to the Japan Sea, whereas 11 genera are peculiar to the Pacific coast, the remaining 6 being common to both regions. In this respect the discovery made shortly before by Nakai of some endemic arboreous plants in Dagelet Island off the east coast of Korea, is of special interest, as they indicate somewhat the nature of the vegetation of a forest-covered land, once connecting Japan and Korea.

The intrusion of some tropical or subtropical elements, such as *Cersidiphyllum japonicum*, Phellodendron, Rhus, Lespedeza, Lindera and Ardisia, far north in the temperate region can be taken as a peculiar feature of the Japanese flora and partly explained as the influence of the warm oceanic current bathing the greater part of the coast of Japan. On the other hand, historic factors can not be overlooked in the consideration. Fossil remains closely related to the above mentioned species were found in the Tertiary beds of northern Asia, indicating a prevailing warm climate at that period. From Sakhalin even the discovery of Tertiary fossils belonging to Ginkgo, Sequoia and Cycad is recorded. In the glacial period, set at about the end of the Tertiary epoch, some of these tropical plants might have migrated, or been driven, southward to the present habitats. Evidences of glaciation have been found recently by Yamasaki and others, though not referable to any definite geological period, in the mountains of central Japan. The effect of refrigeration might then not have been so severe as to eliminate altogether these floristic

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elements. Or, it is also possible, that they regained the northern posts after the subsidence of ice.

Recently the origin of the Japanese alpine flora was made the subject of careful study by Koizumi. Among some 400 species studied, about forty per cent are of endemic or autochthonic nature and forty-five per cent belong to heterochthonic, boreal, or circumpolar elements, which the author considers to have migrated southward in the Pleistocenic glacial period by way of the Bering-Okhotsk land mass, taking one of the routes: Kamtschatka-Kuriles-Yezo or Kohotsk-Sakhalin-Yezo. H. Takeda, who made a careful study of some 300 species of vascular plants collected in Sikotan, the southermost island of the Kurile group, expressed the view, that the migration of boreal elements in Yezo and Honshiu took place more likely through the Kuriles than through Sakhalin. In fact all geological and paleontological evidence tends to indicate that from the end of the Tertiary epoch until the Pleistocene an extensive land mass developing in the Bering Sea region connected northeastern Asia, including Japan with Alaska, thus affording a common birthplace for the floristic elements inhabiting these regions and that portion of the North American continent lying west of the Mackenzie River basin. However, the well known argument of Asa Gray, that the flora of Japan is so intimately related to that of the eastern coast of America, that sixty per cent of plants from the former are to be found also in the latter region, may hardly be maintained, owing to the inaccuracy in specific identifications made in his time. The arcto-pleistocene or glacial elements must easily have gained footing on the mountains of northern Japan, the grounds having been often through active volcanic action, laid bare and thus made suitable for the invasion of these plants. But also in middle and southern Japan, even in Yakushima, lying south of Kiusiu, a sporadic occurrence of alpine plants belonging to the circumpolar and Bering elements is to be found on the summit of mountains which lie at present considerably below timber line. Such might be taken as relics of an extensive arctic flora flourishing under the colder glacial climate once prevailing in these regions. The adjoining regions of the Asiatic continent have been recently explored by several Japanese botanists. While professor in the University of Peking, Y. Yabe made a careful floristic investigation of

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the Province of Chili and the northeastern part of Shansi. He describes in a paper, now in press, some 970 species of vascular plants, among which 58 are new to science or to the region, showing as a whole the floristic characters related either to Himalayan or Ural-Altai regions.

In this short communication I can not enter into details of work done by Japanese botanists on the lower cryptogams. Marine algae have been most thoroughly investigated by K. Okamura and K. Yendo. Much has been done also on fungi by M. Shirai, K. Miyabe and their associates. Lichens are studied by M. Miyoshi and mosses by S. Okamura and others. Many contributions to the general problems of botany can also not be discussed in this place.

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LAS PLANTAS MEDICINALES UTILIZADAS POR LOS FILIPINOS

By Leon M. Guerreo

(Abstract rendered into English by William E. Safford)

In his introductory remarks Dr. Guerrero stated that he did not pretend to treat the subject exhaustively, but that he wished to call attention to the great value of many of the plants and plant-products of the Philippine Islands as medicines, which attracted the attention of early explorers, botanists, and physicians. A great number of these plants are already known; many more remain to be identified. In this connection Dr. Guerrero called attention to the valuable service rendered by Elmer D. Merrill, Director of the Philippine Bureau of Science. Dr. Merrill has brought to light many new species and he still continues this important work, at the same time correcting errors of previous writers and establishing the synonymy of botanical names of plants independently described by several botanists.

Information relating to the application of plants reputed to have medicinal virtues has been obtained from native herbalists and dealers in drugs, whose ideas have, in many cases, been more or less colored by the superstitions of the primitive inhabitants of these islands. In order to assist the laymen in the identification of these plants the vernacular or common names have been added. In some cases confusion has resulted from the application of the same name to several species and in others by the application of several names to a single species. Errors arising from these causes demonstrate the necessity of having one recognized valid botanical name for each species. This name, in the Latin language, will be the same in all countries no matter what the spoken language may be. Dr. Guerrero called attention to the necessity of great caution in accep ing the statements of enthusiasts regarding remarkable virtues supposed to be inherent in particular plants, and also to the wisdom of comparing plants reputed to be valuable for medicine with closely allied plants of other countries. He also called attention to the fac that many native plants had been erroneously regarded as identical with plants of other countries to which they bore more or less resemblance; so

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that certain lists of Philippine plants contain the names of species which do not occur in those islands. In addition to native plants used in curing diseases Dr. Guerrero referred to others used as poisons, narcotics, or love potions.

After giving a list of the principal writers on systematic and economic botany of the Philippine Islands, the paper closed with a "Lista de las plantas medicinales de reconocida importancia y mas populares utilizadas por los Filipinos." This paper will be published by the Philippine Bureau of Science. It is interesting to note that a great many of the plants included in Dr. Guerrero's list occur in Hawaii, some of them introduced through human agency in prehistoric times, others in recent years.

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WORK IN ALGAE AT THE PUGET SOUND BIOLOGICAL STATION

BY T. C. FRYE

The region is rich in species; about 75 are common, exclusive of unicellular forms. Some of the larger ones among the Phaeophyceae, notably Nereocystis and Costaria, are very abundant, and comprise the major portion of the vegetation along the shore. The abundance of Nereocystis and its economic importance have led us to work with it more than with any other forms.

Taxonomically we have done very little. Some work was undertaken in both green and red algae, but awaits the completion of work on Northwestern algae by Setchell and Gardner. This sumer work on the identification of our diatoms was begun.

Perhaps half a dozen or more morphological papers have been completed, mostly on the brown and the green algae. These are usually short, intended to clear up a definite species or a definite point and completed in one to three months. Long problems cannot well be undertaken because most of the workers are at the station for the summer only.

In ecology we have undertaken the mapping of the algae along the shores of some of the nearest islands, and indicating the associations. Most of the work in ecology, however, has been experimental, with a view to determining some of the factors which govern the distribution vertically and horizontally along the shore. We have shown that desiccation is a factor, possibly the chief one, in the distribution of algae vertically above the low tide line, and that light and acidity are factors in the distribution of Fucus, and some other species.

Economically, the station was worked on the production of food from kelp. Among these products are fertilizer, pickles, candied citron substitute, and algin. The cost of drying prevents the use of kelp on a large scale as a fertilizer at present, although there is one factory on Puget Sound. Candied citron substitute and pickles have never been attempted on a commercial scale.

In experimental morphology work was completed on many algae, determining the region of growth, the effect of retarded growth, the result of mutilation, and the rejuvenation of parts.

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In physiology the composition of the seaweeds, notably Nereocystis has been studied. The abundance of Nereocystis, its rapid growth, and the uniformity of temperature in sea-water, makes the region highly suitable for physiological work in which uniform temperature is required.

In this short resume credit cannot be given to the individual worker, but most of the work at the station will be found in Publications of the Puget Sound Biological Station, of which the second volume is now nearly complete.

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THE STUDY OF PACIFIC OCEAN ALGAE

By Josephine E. Tilden

(Abstract Prepared by the Chairman of the Section of Botany)

A systematic study of the marine and freshwater species of the algae of Pacific countries would be a work of great importance. Too much stress can not be placed on taxonomic work as a foundation.

Information should be gathered relating to the geographical distribution of the Pacific Ocean species of algae.

During the recent war the Government made an investigation into the fertilizer resources of the United States. As a result, the great kelp beds of the North Pacific Ocean may in the future be used to supply the potash needed in commercial fertilizers.

In Japan, China, and many Pacific islands, seaweeds form an important article in the diet of the common people. As more is learned about the chemical composition and food value of these plants, their use may extend to other countries.

A list of names used by the natives of Pacific countries for different kinds of algae, accompanied by descriptions of native uses of these plants and by records of myths and stories in which their use was indicated, would be of the highest value to the anthropologist.

The geological aspect of algae—as calcareous pebbles or concretions in freshwater lakes and streams; as calcareous and silicious formations laid down in the vicinity of hot springs and geysers; as deep sea deposits—affords problems requiring deep study. In recent years another subject for geological investigation is indicated—that relating to the part played by various species of lime-secreting green and red seaweeds in the building of the so-called "coral" reefs.

Observations should be made by the vulcanologist as well as by the algologist on the very simple forms of plant life—the blue-green algae—which occur in steam cracks and in the hot water of dripping cliffs in the vicinity of volcanoes.

The algae constitute the primitive food of fishes. The secondary food supply of fishes is made up of crustacea in the ocean, wherever conditions are suitable for their growth. The least physical or chemical change in these conditions may cause

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them to disappear, and in turn, the animal forms dependent upon them.

Taking all of the above facts into consideration, there is indicated a pressing need for an immediate and critical investigation of freshwater and marine plant life.

The following methods of work are recommended:

A. A series of "source books," which shall contain, under one cover, so to speak, all the algological data, based on Pacific material, published up to the present time. Material for this is at hand. With sufficient facilities and assistance, the books could be published within a year's time. The scope of such "source-books" may be understood by reference to the volume: "Myxophyceae." Minnesota Algae, vol. 1.

B. A systematic survey of the entire Pacific Ocean should next be begun, with the series of source-books as a foundation. Two expeditions would need to be fitted out, and two years' time should be allowed for the completion of the work.

The field of observation of the first expedition should include the North American, South American and Asiatic shores, from Cape Horn to Alaska and from Bering Sea to the Malay Peninsula.

The second expedition could take advantage of the regular Pacific steamship lines, with the use in certain localities of trading boats, fishing boats, lighthouse tenders and pilot stations. This expedition would explore the island groups of the Pacific Ocean, New Zealand, and the eastern shores of Australia.

C. The leaders of these two expeditions, with certain members of both expeditions, should do the preliminary work of Easter Island, in order to have an opportunity of planning together in the field, with the object of making the recording of results uniform in detail.

D. Each expedition should include in addition to a leader and a secretary, about a dozen workers: three collectors for plants and animal plankton, bacteriology (meteorological, chemical and physical data); three collectors for marine zoology, algal contents of stomachs of animals, and other zoological data; four collectors for the largest algae, botanical, anthropological, geological data.

E. Collections to be made: algae, bacteria, marine animals, stomachs of animals, samples of sand and rock bottoms, photographs, moving pictures.

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F. Data to be accumulated: temperature of water and air: salinity, acidity, currents, tides, light conditions, depth; zones of distribution; abundance; records of parasitic and epiphytic organisms; kind of rock material to which specimen is attached.

G. Specimens of plants, animals, animal stomachs, and rock samples to be sent to experts and to be finally deposited in sets, in 50 leading institutions of the world.

H. Results: Important contributions and monographs should be ready for publication within five years.

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NECESSITY FOR BOTANICAL EXPLORATION IN THE PACIFIC

(Prepared by the Section of Botany for presentation to the Conference.)

It is evident that systematic botany is the basis of all other botanic work in Polynesia, as elsewhere; for to correlate all other lines of investigation it is necessary that the name and exact position of the species should be known.

Botanical exploration of Polynesia has been desultory. Some areas have been rather intensively explored, some slightly explored, and others almost wholly ignored. While certain local floras have been published on various parts of Polynesia, yet no single island group has been so extensively explored that we may claim its flora to be "known." Exact information as to what has thus far been accomplished in the field of botany of the islands of the Pacific should be presented. The bibliography of the subject has already been worked up by the U. S. Department of Agriculture and exists in the form of a card catalogue in the library of the Bureau of Plant Industry.

In published floras, even where the species of the higher groups are comparatively well known, as in that of Hawaii, an enormous amount of work still remains to be done on the lower groups, including the algae, fungi, lichens and mosses. For a proper interpretation and correlation of the Polynesian flora, botanical exploration must be general. Regions slightly known from a botanical standpoint must be thoroughly explored, and at the same time regions already visited by early scientific expeditions must be revisited and intensive exploration initiated. The recent additions to the flora of Hawaii, supposed to have been thoroughly known, show the necessity of such work. Moreover it is of the greatest importance that comprehensive collections be made in historical areas in Polynesia, so that the systematist may have at his disposal topotype material. In the larger islands botanical exploration must be continuous over several months or a year, especially in those regions where there are pronounced wet and dry seasons. In the case of some species anthesis is continuous, but in the majority of cases species flower and fruit at certain definite seasons. While in temperate regions the collection season is limited by climatic factors, in the tropics the collector must work in the field in all months.

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Special attention should be paid to ethnobotany; for in certain regions essential data on the uses of plants and plant products by the natives must be secured while it is still available. Vernacular names of plants are of special importance in throwing light on the interrelationship of native tribes and as an index to their possible origin and distribution. An example of this is shown in the names of such important economic plants as the sugar-cane, the coconut, the breadfruit, the taro, and a number of fiber plants and trees which have accompanied the Polynesians in their migrations and have carried with them their vernacular names, by means of which they may be traced back to their early home in the Malayan region. The method of preparing plant products should also be carefully noted, such as the preparation of poi from the taro root, the preparation of a drink from the root of *Piper methysticum*, the manufacture of bark-cloth from the inner bark of the paper mulberry, and the braiding of mats from pandanum leaves. Such notes help the ethnologist to group tribes having similar customs and similar arts.

New methods must be adopted in current field work. It should no longer be permissible that collectors be content to prepare their botanical material accompanied only by strictly botanical notes. He should secure all possible available data regarding local names uses, and if possible products of the plants collected, such as fibers, resins, dyes, oils, medicines, and the like. All data should accompany the actual specimens. It may be recorded on a field label like that developed by Dr. Merrill in his Philippine work. (See paper in this volume.)

The collector must secure a comprehensive series of specimens representing each number of species collected. The average number of duplicates should be between 10 and 15. This material will not only show ranges of variation but the duplicates will be available for distribution and exchange. Plans should involve supplying duplicates not only to Pacific institutions but also to the larger botanical institutions of the world. Ample and valuable duplicate material available from remote regions is the best possible means of securing attention from the older institutions of Europe, especially those institutions in which the essential Polynesian types of previously described species are preserved.

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FISHERIES OF THE PACIFIC

OCEAN PASTURAGE AND OCEAN FISHERIES

By W. E. Allen, Scripps Biological Institute

(Presented by invitation of the Committee on Program. Read by H. F. Moore.)

Among the more prominent of man's fundamental interests in the sea is that of food supply. For primitive man that was the sole and essential interest. For civilized man that interest is more or less completely overshadowed by interest in transportation, but it is still permissible to say that production of marine foods is of vital importance and that the degree of its prominence in our thought merely varies with the directness of our dependence upon such foods. Very properly then, we who are here resident upon these favored shores of the broad Pacific, should closely scrutinize all phases of the great problems involved in maintenance or extension of the food resources at our gates.

It is a universal tendency of human kind to be content with the obvious, to give attention to gross phenomena, to ignore primal causes and to hope to evade final results. Choice fish, fresh, iced, dried, smoked, pickled and canned, has been easily accessible to most of us. We visit the ocean shore and see great numbers of fish. We view great fleets of fishing boats, the very existence of which indicates a sufficient supply of fish to assure their upkeep. We read in the newspapers about the large catches, in magazines about the fisher folk and their ways, and in various books about the romance and the tragedy and the commercial and political power bound up in fisheries operations. With such varied and cumulative evidence before us, it is not strange that most of us think of fisheries problems as concerning nothing but fish. My part in this program is to call attention to the fact that these problems go deeper than that, and that their solutions demand excursions into fields vastly remote and unfamiliar to most of our people. For the sake of brevity, I must confine myself mainly to that one of these fields which affords the rock bottom upon which to build for any adequate understanding of marine life.

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I refer to the field of knowledge of the phytoplankton, that vast assemblage of plants invisibly small, which alone is capable of manufacturing from raw materials in the open seas those complex substances which can be used for the sustenance of higher forms of life. Because it, like the green herbage of our pasture lands, manufactures these necessary materials, and because, also, it, like the land pasturage, directly or indirectly furnishes foods for all animals associated with it, we sometimes call it the pasturage of the sea.

Our own personal dependence upon land pasturage is fairly obvious though indirect. Green grasses and legumes manufacture from soil waters and gases of the air starches, sugars, oils and proteids which can be eaten by cattle, sheep, swine, or fowls, and worked over into still other sugars, oils and proteids peculiar to their own bodies. We in turn eat the flesh of these animals or the milk or eggs produced by some of them, and then work them over into our own substance. In some cases we make direct use of the plant materials without the intervention of the other animals. It is fairly plain to most of us that neither we nor the domestic animals can manufacture our own flesh and blood from such simple materials as soil water and atmospheric gases.

Our dependence upon ocean pasturage is much less obvious, partly because few of the oceanic animals which we use feed directly upon this pasturage, and partly because the individual plants composing it are so small as to escape our notice. It is also possible to be misled by the notion of certain investigators that marine animals (even including fishes) may derive a considerable proportion of their nutriment by direct absorption of certain materials dissolved in sea water.

It is, however, becoming more and more evident as knowledge increases, that the relationship of living things to each other are strikingly similar in sea and on land. Probably all of us make more or less use of salmon for food because salmon flesh is easily and quickly convertible into human flesh. mackerel and herring. Mackerel live on still smaller fish or squid and small fish. Squid in turn have used fish such as mackerel and herring. Mackerel live on still smaller fish or when such food is scarce, they may use small crustaceans or may even come directly to use of the ocean pasturage itself. At any rate, the small crustaceans feed directly upon this

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pasturage. It is also true that a good many predacious fishes use the plants for food while in very young stages of development. The pasturage in turn maintains itself by using the energy of sunlight for manufacture of food stuffs. When we think in terms of salmon it seems a long way to the original food factories located in the tiny bodies of the marine plankton plants. When we think in terms of mackerel or sardines or mussels or oysters, it is only a brief span from tiny factory to ultimate consumer. In either case, we may be sure that marine foods which we eat are just as truly derived from plants as is the case with any land food.

Now it may seem strange that plants of the open sea should be able to supply the requisite quantities of food for so many animals if their size is so small. A very common kind of these plants in Southern California waters (*Nitzschia seriata*) is about 1/4000 of an inch in length. But small size is compensated by vast numbers and wide distribution. When the particular plant which I have just mentioned is present in very moderate quantities, there may be about 300,000 individuals to each quart of sea water, or about twenty to each drop of water. But sometimes individuals of this kind may be so numerous as to give a brownish color to the water in which case there may be some millions in each quart of water and some hundreds in each drop of water. We have a record of areas of brownish water of this character some fifty miles in extent and probably some fathoms in depth. Surely the amount of plant material which occurs beneath such an area compares very favorably with the plant material found upon a similar area of pasture land. If this marine plant happens to furnish a nutritious food for sardines or for the minute animals which they may eat, such an area is probably more productive of fish flesh for human consumption than is a similar area of ordinary range land productive of the flesh of range cattle.

A moment ago I mentioned the fact that some investigators had got the idea that many marine animals thrive over long periods of time by simply absorbing nutriments which were thought to occur dissolved in sea water. There were two principal reasons for this view, one the fact that so many marine animals are caught which have no traces of food in their digestive tracts, the other the supposition that large

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quantities of nutrient substances had been found dissolved in sea water. Careful investigation has shown that for animals no usable quantities of such materials exist in the dissolved condition, but no full explanation has yet been found for the frequency with which the digestive tract of animals are found empty. I have noticed the puzzling fact that the tiny animals which directly feed upon the phytoplankton (or ocean pasturage) are seldom, if ever, found in greatest abundance at the time that the pasturage seems to be most abundant. So we find that there are a number of reasons why we may easily overlook the importance of the pasturage of the sea.

I hope that I have now indicated sufficient ground for the assumption that without conservative plant life in the sea there can be no animal life in the sea, that is to say, no fish and no fisheries. If the pasturage be scant, the animals will be impoverished both in flesh and in numbers, this being no less true of our fishes merely because most of them eat other animals. If the pasturage be abundant the animals may increase both in flesh and in numbers. These effects will be almost immediately seen in the case of very small animals which live altogether upon plant food. They may not be observable for months or years in the case of animals so large as any of our important food fishes. Even then, the effect must be sought for. It does not appear without some careful study. Perhaps the best example of such study which has yet been made is that which concerns mackerel catches in the English Channel for British markets. This study was made by members of the scientific staff of Plymouth Laboratory in England, and while very imperfect, it does indicate influence of plankton distributed upon the size of commercial catches of mackerel, and it indicates that more or less sunshine in February and March means more or fewer mackerel for market in May. This is probably because much sunshine in February and March means much pasturage for the minute animals which form a large portion of food for mackerel in succeeding months. With plenty of food the mackerel thrive and they stay within catching distance. With scanty food they probably go elsewhere.

In the case of larger fishes, a lack of sunshine in February and March of one year may cause so poor development of pasturage that the very young fishes cannot find food and

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they may starve by millions. If such a fish requires three years to reach maturity we may not see the evil effect of this starvation until we note the small number of adult fish in the third year. On the contrary, if we knew nothing of causes we might be surprised at excessive abundance of marketable fish in the third year after a season of much early sunshine, heavy pasturage, vast numbers of microscopic animals and thriving little fishes.

Such a year of abundance would almost certainly cause a great increase to be made in fishing equipment for the next season which, however, might be exactly the lean season due to starvation of vast numbers of little fishes which has just been referred to. Not only would all fishing industries handling that fish suffer loss, but it might easily happen that the concentrated assault upon a sparse population would deplete it beyond recovery.

Assuredly now if pasturage is thus essential it is important for the continued success of our fisheries, their efficient maintenance, possible expansion and better development that we should know something about it.

Before an intelligent stockman selects a range, he examines its capacity for furnishing food for his cattle. The amount of his cash outlay, the size of his establishment and the number of cattle which he places, is determined by his judgment based on this examination. Closer acquaintance with the range may cause him to reduce his activities or it may enable him to make important extensions. He may find it better adapted to some types of cattle than it is to others, or that according to season, one part of the range may be more valuable than another. As compared with fisheries his judgments are easily reached and his adjustment simply and easily made. The fisherman is confronted with a much more obscure and intricate set of conditions. The ocean pasturage is nearly or quite invisible. Its examination requires expert knowledge, special equipment, and a complex series of tedious operations. At best it does not seem probable that he can get any very dependable conclusion as to the plant fertility of a given area without a good many years of expensive cooperative effort. It seems to him much more immediately satisfactory as well as more simple to just go ahead on the basis of luck. But we too are interested in the continued success of the fisherman

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just as we are interested in the success of the stockman and for exactly the same reasons that we try to help the stockman increase his production, we ought to do everything possible to help the fisherman to increase his production.

But some one says that it is not possible because there is no way in which man can increase the fertility of the sea or control the distribution of its inhabitants. To that we must reply that a problem is not to be rated as insoluble merely because it is intricate and difficult and that partial solutions may have very high practical values even if complete solution is impossible. What then are the best lines of attack upon this problem of the fertility of the sea and how can it best be approached?

Let me say first that it must not be supposed from what I have already said that the fisherman himself can do nothing. Mr. C. E. Bullen of the Plymouth Laboratory made quite a study of fishermen's signs as well as of the microscopic things to be found in the water where mackerel could or could not be caught to advantage. He mentions such distinctions as "stinking water," "yellow water," "blue water," and "green water," and notes the fact that the more intelligent fishermen were quite successful in predicting success or failure of hauls under certain marked conditions. Some of us are sufficiently experienced to be able to verify that sort of thing from our own observations. If we could induce even a few fishermen to keep fairly dependable records along such lines as this, they would not only have some immediately practical value but a real usefulness in supplementing more specific scientific study through their gross indications of various conditions of distribution of living things.

But, of course, even if such cooperation by fishermen could be secured, the main bulk of the work of investigation must always be of a highly specialized character. On account of the relative inaccessibility of the sea it must also always be very expensive and difficult.

Practically the only available method for study of ocean pasturage (phytoplankton) is by taking samples of the plants from the points where found to some laboratory where they may be examined. After gaining acquaintance with the different kinds of plants in a region, it is necessary to accumulate records of where, when, and under what particular

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conditions they occur or live and thrive. In order to do this it is necessary to estimate the numbers found in each catch. Such an estimate must be based on actual count of a certain fraction of the catch by use of the microscope. In order to have much value the catch should be made from a measured quantity of water. Estimates obtained by such methods may be properly tabulated, classified and carefully recorded in connection with statements of every known condition which might possibly affect the organisms and determine their presence in a particular locality in any observed quantity. When accurate records have been accumulated over a period of time sufficiently long, sometimes years, sometimes decades, or even centuries, it may be possible to state with very considerable confidence the amount and kind of pasturage which may be found in a certain place under certain conditions. If these conditions of existence can be accurately identified for such simple basic organisms as the phytoplankton, that identification will serve as a basis from which to work out similar identifications for more complex organisms. Meanwhile there is always the chance that a clue may be found to a short cut to some of this valuable information.

As a matter of fact it seems highly probable that certain features may be brought out rapidly. The little which I have already said concerning fishermen's signs suggests a possibility. For example, there is a statement by Mr. Bullen to the effect that "yellow water" points to good catches of mackerel, while "stinking water" indicates light catches or none. This led him to determine the contents of the different kinds of water with the result that "yellow water" was found to contain enormous quantities of two certain kinds of copepods, while "stinking water" contained certain kinds of microscopic plants. We have found on our own shores that many fish as well as other animals are found dead on the beaches when there is excessive abundance of such microscopic plants as *Gonyaulax polyedra*. With such points of information from which to start we may soon find that excessive production of certain kinds of plants in a given area will mean poor catches of fish there for considerable periods of time, possibly for one or more seasons. It is analogous to a situation which might occur on land if loco weed should be excessively abundant for a season in a given area.

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After all, however, the main thing which is to be expected from careful study of ocean pasturage is a more exact knowledge of the ways in which oceanic conditions of life produce their effects. An exact knowledge of the good or bad effects of slight changes of the amount of salt in the water give valuable clues to the ways in which such changes affect other organisms. And so with temperature, light, density, and various other conditions. It is almost impossible to make direct study of these things in the case of animals, especially fishes, because they can move about too much, they are too large and too hard to catch, and it is impossible to examine such vast numbers of them. We can not be sure that a given condition in which we find them is either normal or abnormal.

In conclusion let me emphasize the fact that the problem of the relationship of ocean pasturage to ocean fisheries is a very important and fundamental one. Because of its difficulty it requires all sorts of cooperation as well as expert work. Only the other day Mr. Dill, Chemist for the Canners' Association at San Pedro, came into my laboratory room with a lot of questions as to when copepod and other plankton were most abundant, and as to how it was distributed. He explained briefly some of his observations on fat content of sardines and mackerel, and we soon found that we were both eager to get at explanations of a lot of the same phenomena, and I think both of us could see that ways might be worked out in which we could be mutually helpful in hunting for these explanations.

As I see it, we need a great many workers of several kinds, a great many standard points of collection and the utmost possible degree of standardization and simplification of method. Observations ought to be made continuously with great frequency in the standard localities and by means of standardized series in other localities. There ought to be thorough standardization of methods of handling materials and of recording results. Our own Institution has already made a start in this direction, and we wish to do our part in establishing such procedure on our whole coast.

DISCUSSION

MR. MAYOR: Sea animals are generally well fed. The food supply is abundant. Of course in the tropics we do find less animal and plant life than in the colder regions. The plant life in Samoa was so meagre

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that you would say there was none at all. But that is because it is submerged and rests on the bottom. The animals do not die of starvation. Take the coral for instance: I have never seen any starving corals. Whenever there is a great rain, thousands and thousands of corals are killed. Once in Samoa after a rain the corals were covered with mud. They couldn't get food. They did look starved when I uncovered them. It is some accident or catastrophe that is fatal to fish, not the absence of food supply in the ocean.

MR. MOORE: I agree with Dr. Mayor that adult fish do not often die of actual starvation. But there is a great difference in the condition of fishes in regard to fat content at different times, and this is due in part to the relative abundance of food. The important factor is the presence or absence of plankton.

Fish will not remain where there is a scarcity of food. On the southern coast of New England a few years ago there was an enormous quantity of plankton. The fishermen made a heavy catch of mackerel. The following year there were practically no mackerel. It was found that there was an extraordinary scarcity of plankton. We do not believe that under such conditions the adult fish are starved to death, but they do go elsewhere to seek food and the fishermen can not find them. It is not improbable, however, that a paucity of plankton may result in the starvation of the pelagic larvae of fishes, whose more feeble powers of locomotion do not permit them to go far in search of food. We do know that there are years in which something happens that is adverse to the production of an adequate number of young fish. This is notably the case with the herring and it frequently happens that for several years the catch is practically limited to fish hatched in one year, with few or none of the year classes of the several seasons immediately preceding or following. This may be due to unfavorable temperature or salinity conditions but these conditions may act indirectly through the food supply as well as directly on the fish eggs and larvae themselves. We may not be able to correct a deficiency in plankton, but if we knew that it existed during a given season in a given part of the sea, we might at least use the knowledge in advising the fishermen not to waste their time in futile effort but to go where fish food and consequently the fish might be found.

MR. BARTSCH: Some years ago I listened to a most instructive discourse by Dr. Johan Hjort on this topic. He pointed out that the herring catch in Norway could be foretold by about four years by the temperature conditions of the currents as they approach the coast of Norway, because upon the temperature of these currents depends the growth of the plankton on the spawning grounds of the herring. The young herring fry in turn depends upon the plankton. If the temperature then, is too low to produce adequate food, the output of herring will be low for the year, etc., etc.

Fridtjof Nansen has worked out wonderfully the interrelationship of ocean currents and their effect upon the climate of Norway so that by a study of currents they will be able to tell the fishermen that it will be more profitable for them to go cutting wood four years hence than to fish for herring.

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AN ECONOMIC SURVEY OF THE SEA

By J. Russell Smith, Columbia University

(This paper is the preliminary and unrevised report of the Committee on an Economic Survey of the Sea appointed by the Division of Geology and Geography of the National Research Council. The committee consists of J. Russell Smith, Chairman, Isaiah Bowman and Walter S. Tower. Presented by invitation of the Chairman of the Conference.)

What new services can marine organisms render to humanity?

Sir John Murray, the oceanographer, has said that the productivity of the sea is equal to the productivity of the land. If this be true, and there is small reason to doubt it, here is perhaps the greatest unused resource within the reach of man. It is commonly estimated that less than five per cent of man's food comes from the sea, and in countries like the United States the figure is lower than that. At the same time we obtain a very small amount of industrial raw material other than food from the sea. This low figure of utilization in comparison with the high figure of productivity shows unrealized opportunities that can only be measured financially in billions of dollars. This may serve as an economic measure of the need for the application of science to the sea.

Knowledge of the sea is of interest to geographers in exactly the same way as is knowledge of the land. Geographers are interested in the results of soil surveys, geological surveys, and atmospheric surveys, as well as hydrographic surveys.

The promotion of work looking toward the utilization of the sea is a proper sphere of activity for the National Research Council because the Council deals with geography. It may be pointed out that we have a fish commission operated by the United States government. It is also true that there is a Geological Survey similarly operated. Yet no one questions the propriety of attention to geology by the Research Council.

To place the life of the sea more fully at the service of man we need systematic scientific surveys, experimentation with products, and education to promote utilization of products.

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Indefinite amounts of work in each of these three fields will result if a body of men give serious and continued attention to the problem of increasing the service that the sea can render to man.

The question cannot be dismissed by saying that this requires oceanographers, therefore leave it to them. For example, in discussing the possible utilization of plankton, Professor Henry B. Bigelow, one of our leading oceanographers, says, "A far more profitable field, I should think, would be to urge upon the public the use of the perfectly good fishes which they now refuse, e. g. the goose fish, the various sculpins, etc." (Private letter Feb. 14, 1920.) Whereupn Prefessor Bigelow then very properly hastened away to sea to continue his researches concerning plankton, a field in which he has very greatly increased human knowledge. A well-known marine zoologist described the situation by saying that scientists working with the sea have often reported great masses of various species, both animals and plants, that promise great use to man if systematic experimentation can be applied. But as this zoologist remarked, the scientists report these facts and then drop the matter. This is quite natural, for why should a man studying plankton stop and give attention to the scallops of which he accidently discovers beds of great richness covering hundreds of square miles? They are aside from *his* field. They are not aside from the field of work here presented.

The problems of economic utilization of the sea if conceived in anything like its full scope becomes primarily one of promotion. First, find what work needs to be done. Then, find some existing organization whose proper work is to undertake it. Lastly, point out and prosecute the remaining untouched or unsolved problems.

Consider for example, a specific problem. Take the case of some pelagic mollusk or crustacean which we know is found from time to time in hordes of such extent that vast quantities could be taken by vessels properly equipped. Two types of questions at once arise.

First, how may these animals be obtained in commercial quantities? To obtain them regularly requires exact knowledge as to where and when they may be found and how they may be caught and handled. This means that we need to know what controls the food supply, assemblage and movements of

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the plagic hordes. This may require careful, systematic, and long continued surveys of large areas of the sea by specially equipped vessels, which may at the same time gather information of use and interest in many other ways.

Second, how may these mollusks or crustaceans be used?

1. For human food. This may require work by (1) educational institutions interested in domestic science, or in physiological chemistry and nutrition. (2) by special foundations interested in health problems, or in improving the condition of the poor. (3) by food manufacturers, restaurateurs, fishing and other industrial corporations. Any of the above might be persuaded to make experiments or investigations because their interest was attracted to the possibilities of this field of work. Lastly, investigation of the human food aspect of the question would probably result in knowledge of which the proper utilization would require much definite educational work such as is indicated by Professor Bigelow's statement that he thinks it "a profitable field to urge upon the public the use of the perfectly good food fishes which they now refuse." This is in itself a real task because of the senseless conservatism of man with regard to new foods. This phase of the work of benefitting man is distinctly educational not to say propagandic.

2. Animal food. If our mollusk or crustacean promises greater use for animal food than for human food, it is of particular interest to swine growers and poultry growers, and as a problem in either of these fields it might properly and easily be undertaken by any one of several of the many experiment stations now organized in the United States and working in many fields of experimentation, with varying interests according to local conditions and the interests of the staff. It is a problem in promotion to get these stations at work on these problems which in all propriety belong in their field.

3. Fertilizers. If our mollusk or crustacean promises to be of greater use as a fertilizer than as food, this again might appeal as an object of pioneer work to many experiment stations, to fishing corporations or fertilizer manufacturers.

It need scarcely be mentioned here that an indefinite number of problems somewhat like the above actually does await solution.

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At this point it should be emphasized that the great problems now facing the American public in its food supply is not new foods for people but new foods for domestic animals. People change their food habits with great slowness, but prices indicate that we are in an acute situation with regard to protein foods for our great protein supports, poultry and swine. If by experimentation the sea can be made to give a cheaper substitute for cotton seed meal, linseed meal, ground meatscrap, tankage, or dried fish, an industrial outlet is at once provided for a product worth tens, and shortly hundreds, of millions of dollars per year, and human food supply is at once though indirectly benefited.

It is desirable to promote scientific work in all directions, abstract, systematic science that may or may not promise utilities. The scientist knows, of course, that on the average there is no such thing as useless science and that the difference between abstract and applied science is fading away. Nevertheless, the low state of systematic surveys of the sea and our essential ignorance concerning it can be advanced as proof of the difficulty of getting support for so-called abstract rather than applied science.

There are really two ways of getting work done on the remoter problems of science. One is the direct appeal for the abstract science which will of course produce incidental utilities. This appeal is difficult to make with financial success. The other and easier appeal is to start specific industrial problems which in their development promptly create and demonstrate the necessity for abstract and systematic scientific work. It is easily possible that the best way to get certain systematic marine surveys made is to start teaching people how to use some marine product now unused.

Your committee believes that the time has come when the survey of the sea can be greatly promoted by a type of scientific promotion indicated by the above-stated hypothetical case of the problem of the pelagic mollusk or crustacean.

It is not primarily a problem in oceanography, marine zoölogy, marine botany, fishing, human nutrition, physiological chemistry, plant nutrition, swine feeding, poultry feeding, food preserving, or food introduction. It is, however, easy to see that many or all of these activities might be called into service and

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also many others in the solution of any one of many problems that await.

If the field is conceived in some approach to its real size, and a canvass made of the work now going on, specific problems of great promise will begin to take definite shape. It will then appear here, as it has already appeared in other fields of work, that much increase in work will be achieved by existing agencies merely because there is some central body of informed men who can serve as a clearing house. It is doubtless true that many expeditions have gone on specific and costly errands when, without proportional increase in cost, they might easily have been enlarged by the addition of members who could have carried on other investigations in some of the almost innumerable fields of marine research.

One of the definite needs of the day is a strong, permanent organization of some sort having for its work the whole field of promotion of knowledge of the sea and the utilization of its resources of any and all sorts.

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THE FISHERIES OF JAPAN

By K. Kishinouye

The fishing industry in the Japanese Empire is no doubt the most important food source of our nation, as our people feed on rice and fish chiefly. As you well know, the empire of Japan is a group of small and thickly populated islands; and from the study of shell-heaps I found that the islands of Japan have been from ancient times the center of a very big fishing industry. The people living on our islands in prehistoric times were of course different from the Japanese of today, but they caught almost the same kinds of fish as do the fishermen of today. They caught fish along the shore and also deep water fish. It was a great surprise to me when I found skeletons of bonitos and our common tunny in large quantities in the collections from shell-mounds. At first I thought they came from fertilizer, but on close investigation I was assured that the farmers of that district had never used fertilizer. The deposit consisted of a deep layer of soil never disturbed by people, mixed with crude pottery and fishing implements made of horn and bone. Most of the fish esteemed by our people today were taken by the prehistoric people living in our islands, in much the same manner as today.

In consequence of the small amount of land to be cultivated, the people living on the small islands get animal food only from the water, for they must spare some land for the purpose if they wish to raise cattle or fowls, and naturally they go to the sea for their animal food. So our fishing industry was developed and our people are used to the animal food obtained chiefly from the sea. We also use our algae to a great extent for food and in the manufacture of glue. We use also marine invertebrates such as jelly-fish, sea-urchins, holothurians, tunicates, besides cuttle-fish and shell-fish which we collect in large quantities. Fishing in the great depths is also well developed in Japan. The Japanese fishermen catch fish sometimes at a depth of from 300 to 500 fathoms. They sometimes go off shore to a distance of 100 or more miles for the purpose of fishing.

The methods of fishing are also interesting in some respects. The fishermen used to catch fish by scaring and driving them in schools to shallow water. But recently they have discovered that

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this method is not a good one and they generally use the method of attracting the fish to shore or to any place convenient for the catch. The fishermen accomplish this by providing shelter or shade or food, or they attract the fish by the use of electric lights or torches. Artificial banks are also built and many other devices used.

Many interesting kinds of fish lines are in use. To catch fish in very deep water they use exactly the same methods as are used in sounding the great deeps of the ocean. A bar or spreader 3 or 4 feet long is attached to the line and from the ends of the spreader snoods with hooks are hung. Heavy weights are necessary to keep the line straight; a stone is therefore fastened to the middle of this bar. The line must be very slender and very strong. The fisherman sinks it down very quickly to the bottom. When it touches the bottom the strings are loosened and the additional weight is dropped.

Then they haul in the line two or three feet and keep it between two fingers. As the spreader is long the bite of a fish about 1 pound in weight is easily felt, especially as the fingers of the fisherman are very sensitive. When he hauls in the line somewhat the deep-sea fish comes to the surface by means of its own buoyancy because of the distended air bladder.

Now let me explain a long line for tunnies as an example of the sort of fishing implement which is used extensively in different fishing grounds for the capture of certain fishes. The long line is not used in other countries so far as I know for the capture of tunnies.

The tunnies are generally large and very swift swimmers. They go down 100 or more fathoms at once when they bite the hook so that the line ought to be very long, 1200 feet of line generally being used. The long line is buoyed to drift in the layer of water about 10 to 20 fathoms under the surface, depending on the temperature of the water. When the water is warm the line should be kept in shallow water; when the water is cold it should be sunk deeper. As there are 5 species of tunnies in our waters and some of them live in deeper layers of water, the fisherman sometimes uses snoods of different lengths to catch different species at the same time. The hook of the longest snood lies about 40 fathoms or more below the surface of the water. The buoy used at the surface has some bamboo rods tied perpendicular to it and a flag is attached. When the fish bites

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the hook the flag and buoy disappear instantaneously below the surface, and at that moment the fisherman catches the other buoy and then gradually hauls in the line. When the tunny runs about 100 fathoms as it sometimes does it probably strikes the bottom a little tired; then the fishermen begin to haul in the line. But when the fish becomes active again the fishermen slacken the line and let the fish go. When they haul in the line and the fish comes near the surface it is harpooned and brought into the boat. This is the usual way of catching the tunny.

The tunnies swimming near the coast are restricted to three species only. They are caught in large trap-nets, chiefly in summer.

At this point I wish to call attention to a peculiarity in the anatomy of tunnies. I shall not state it in detail as it will bore you very much. The bonitos and tunnies are quite different from other teleostomous fish in having dark red muscles deeply situated in both sides of the vertebral column. But these fishes are classified in the same family as mackerel, and others.

Tunnies and bonitos have very well developed subcutaneous blood-vessels. So far as I know this has not been shown in scientific papers. These blood-vessels are different in different species, genera and families. They are connected with venules and arterioles which form a sheet on the apaxial side of the dark-red portion of the lateral muscle.

That dark-red portion contained in one species of tunny has fourteen times as much blood as other parts of the flesh. In some species of tunnies these blood vessels pass under the third rib, in others under the fifth rib. Besides this plexus of blood vessels, we find two other form of plexuses on the dorsal surface of the liver. One form is found as a thick rod in the trellis under the vertebral column, in the yellow-finned tunny and bonito. These plexuses are probably related to some internal secretion.

In correlation with the dark-red colored muscles I have found many peculiar anatomical features, which will be discussed in a paper now being prepared on the so-called scombroid fishes.

DISCUSSION

MR. FRASER: What is being done in the schools to teach the subject of fisheries?

MR. KISHINOUYE: In the University of Tokyo we have a section of fisheries; also in the University of Hokkaido there is a Fishery Institute belonging to the department of Agriculture. There we carry on education as well as investigation. The course involves three years' study. We also have graduate courses.

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MR. MAYOR: Is it your object to adopt the fishing methods of other countries, or to keep your own?

MR. KISHINOUYE: Japan wishes to keep the old methods of fishing at the same time to adopt new ones if they are suitable. We get ideas from our fishermen, but we give them new methods also. They are proud to do things as their ancestors did them.

MR. EVERMANN: I have been very much interested in the methods of deep-sea fishing described by Mr. Kishinouye. I am reminded of fishing which I once did at the red snapper banks in the Gulf of Mexico, particularly in the matter of the way the fish came to the surface because of the expansion of gases inside their bodies. We fished at a depth of from 50 to 70 fathoms with a large line and a 3½ pound sinker. The lower part of the sinker was cup-shaped, the cup being filled with a mixture of beeswax and lard in order to bring up samples of the bottom. There were two hooks used. When the fish were brought up it was almost invariably found that their stomachs had been forced into their mouths because of the expansion of gas in them, and the spewing or contents were thrown out on deck.

I made the trip to save the spewings. The contents of the stomachs thrown out proved to be exceedingly interesting. In a few days we got many small fish in all stages of digestion from the stomachs of the large ones. Sometimes they were nearly digested; sometimes they were still alive. We got 13 different species all new to science. They could not have been gotten in any other way. They were too small to be caught on a hook and line. By letting the red snapper catch them first, then catching the red snapper, we got the small fish we wanted. Dr. Kishinouye's drawings are of extreme interest. They show an extraordinarily good piece of work. The scombroid fishes have been studied only superficially without cutting up the fish, but he has gotten deep-seated anatomic structures and new generic characters unknown before. The specific characters which he gets by cross sections of the vertebrates, the location of blood-vessels, and the character of the muscles, are extremely valuable. I want to express my appreciation of the splendid work Mr. Kishinouye has done in the study of scombroids.

MR. EDMONDSON: Is there evidence of depletion?

MR. KISHINOUYE: Yes. We are inclined to believe that our important fishes are decreasing. Of course the total amount of animal food will remain constant, but in many bays and inlets certain of the food fishes are decreasing, the sardines, for example. There seems to be no decrease in those fish that have pelagic eggs.

MR. EVERMANN: Do they get scambroids near the spawning season?

MR. KISHINOUYE: Yes, large schools spawn near our coasts in July and August.

MR. FRASER: Are you using any conservation methods?

MR. KISHINOUYE: Yes, we have a closed season.

MR. MOORE: Some years ago I visited the fisheries of Japan under the guidance of Mr. Kishinouye. Since that time I have often wondered what our race will do when the land becomes overtaxed, but I am encouraged when I think of the large amount of fish Japan extracts from the sea, and how large a population exists on the small acreage available for tillage. The Japanese fishermen are resourceful and ingenious. Dr. Mayor's question as to whether the Japanese were going to continue to use their own methods suggests to me that other countries could adopt some of Japan's methods to advantage.

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CONSERVATION OF FISH RESOURCES

By C. M. Fraser

In my opinion some definite recommendation as to the necessity of conservation of the fish supply should be made by this Conference. I believe it is quite possible for the human element to interfere very largely in the amount of fish. In the area in which I have done most of my work the striking example is the disappearance of the salmon in the Fraser River. For example the sockeye has become almost a negligible quantity. The Fraser river and its tributaries is the greatest spawning area suitable for spawning salmon in the world. Because the sockeye is the most valuable it has received the most attention, but other species also are going. The King salmon and Silver salmon situation is serious. These species can be caught in the open sea at the Straits of Juan de Fuca and in other places. They are caught when two or three pounds in weight which is a great loss, because if left until maturity they weigh from 9 to 15 pounds. The Chinook salmon case is worse. It may live for 5 or 6 years, but it is often caught when 2, 3 or 4 years. Yet it reaches when mature 70 or 80 pounds. The fish caught now are much smaller than they should be. They do not get a chance to mature. The halibut is of considerable age when it spawns. That makes the situation more serious for this species. With other fish the cod or so-called cod such as the ling cod, are decreasing. The same is true of the red cod and the rock cod. It has become so serious in the last year or two that all the men in the industry feel that something should be done. At a meeting of the Canadian Fisheries Association in June this matter was discussed. The attitude of the younger men in the fisheries is encouraging. They are very much in earnest in their desire to do something to save the situation.

A considerable amount of discussion has been going on for some time between Newfoundland, the United States and Canada as to means of coöperation for conservation of fish. At a meeting of the American Fisheries Society to be held in Ottawa on September 20-22 perhaps some plan may be devised to bring this about—not a large extensive plan but a general get-together on a plan of work to be done in each country. The Canadian Fisheries Association went on record as supporting any movement of that kind and voted to send a delegate to all meetings held any-

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where within a reasonable distance. It is as a representative of the Canadian Fisheries Association that I am here at this meeting. It seems to me the time is more nearly ripe now than it has ever been. We have a large area of continental shelf, a great feeding ground for fish. A great deal of good could be done by a biological investigation of the waters in this area.

The main trouble here as elsewhere is the difficulty of getting men because there is not money enough to pay them. The facilities for carrying on the work are there. I think both Canada and the United States are in a condition of mind to support such recommendations as might be made. If you choose we might go on record as to the necessity of providing men and resources to begin an investigation.

It is not a national question. The fish go into the streams of Japan and Siberia. It is an international question.

[In response to Mr. Fraser's suggestion a committee was appointed to draft resolutions outlining investigations needed in the formulation of regulations for conservation of fisheries. The committee consists of C. M. Fraser, H. F. Moore, Josephine E. Tilden, T. C. Frye, Barton W. Evermann, K. Kishinouye, George F. McEwen.]

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INADEQUACY OF STATISTICS OF FISHERIES

By H. F. Moore

One more matter I wish to present: The question of statistics is highly important in determining methods of conservation. As matters stand now we are without adequate data of that kind. We know in a general way that we catch a certain fish in a given section, but we do not know how it has been taken. The Bureau of Fisheries makes a territorial survey which may cover the country by sections once in five years. In that way it not only gives the total catch by geographical areas, but also the catch by the various kinds of apparatus, which furnishes us in some measure a yard stick by which we can measure the activity or intensity of the fisheries. But that is done only once in five years. We have no way of telling whether the fifth year was a normal or an abnormal year. So while the statistics are reasonably good, they are valuable for industrial rather than scientific use and are not suitable for the biologist who is taking up the study of the effects of the fisheries on the abundance and distribution of the fishes caught.

It seems to me that it might be advisable in connection with the proposed resolutions to include something that will cover that point. I have attempted to use statistics and have been embarrassed by the lack of specific data. This is an important matter to state governments which under the American form of government are charged with the duty of administering and conserving the fisheries by regulatory measures. They are confronted with a situation of more or less doubt as to the actual state and tendency of the fisheries. They can't afford to throw men out of employment and deprive men of food without good reason; but on the other hand they cannot permit the fisheries to run the risk of imperiling the future food supply. We owe it to the men engaged in fisheries administration and regulation that they should be given the means of gauging the quality of their acts and the merits of their regulations.

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THE NECESSITY OF CONSERVATION OF FISH RESOURCES

By Barton W. Evermann

What I intended to say and perhaps shall say will pertain more particularly to problems of the fisheries which need investigations in relation to need of conservation of certain forms of life of the commercial fishes. I refer to the marine mammals.

The largest animals that live in the sea perhaps are the ones least known. Some time ago I looked up the literature on the mammals of the North Pacific. We have in the neighborhood of 44 species of marine mammals in the North Pacific so far as I could learn. Those are the whales and other cetaceans, the seals and carnivores. There are something like 9 baleen whales, 5 sperm whales and 14 porpoises, killers, and dolphins, or 26 species of cetaceans in all, and among them are the largest animals in the world. Very little is known about them—what the species are, what their distribution is or how abundant they are. A little while ago a whaling station was established on the California coast. Even the whalers did not know what species of whale they expected to get but they would make the most optimistic statements as to the commercial possibilities of the whaling industry, stories colored somewhat doubtless for the purpose of selling stock. The company built its plant and went into the business. They have exceeded the expectations of everybody except the promoters. They have for several months been taking on an average one whale a day off the California coast near enough to their station north of Santa Cruz to bring the catch in to the station the same day or early in the morning of the day following. The species caught is usually the humpback.

It is always an event in an ocean voyage to see a whale, even to those who have crossed the ocean many times. They are not so numerous but that the seeing of one is an event to be remembered. On the California coast in the last four months they have taken out 120 whales within 100 or fewer miles of the same place. This represents a serious inroad on that species of marine animal. The states have no regulations because whales are very seldom found inside the 3-mile limit; nor would federal regulation be of any use for the same reason. It is a question for international consideration rather than governmental regulation by individual governments. It is perfectly apparent that

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little or nothing can be done except through international agreement.

Of the 44 or 50 species of marine mammals in the north Pacific there are only two or three that have received much attention. The Alaska fur seal has been written about perhaps more than any other animal in the world. Yet there remains a very large amount of information which we lack about the Alaska seal; and of the Japan seal and other species we know even less. We have studied them to some extent on their breeding grounds and the Japanese doubtless know about the northern migration and possibly a little about the return southward migration. We know something about the Alaska fur seal from the time it strikes the California coast early in February until it reaches Behring Sea in May and June. But as to where it goes when it leaves the Aleutian Islands in late October and November or where it is until it comes up at San Diego in late January or February, we know practically nothing. We do not know whether the three species of fur seals mingle at all, and until we do know whether they mingle we lack a very important factor in their life history. If we find that they do not mix, if they remain entirely distinct the sponsors of the opinion that there are three different species will receive strong support.

The fur seal is now being protected by the international treaty signed by Great Britain, Japan, Russia, Canada and the United States, in which it was agreed to prohibit pelagic sealing. But unfortunately the treaty permits the killing of the seals by the aborigines of Alaska, British Columbia, and the Asiatic coast. That is a very unwise provision, for the natives kill the females, which ought to be protected.

The northern sea otter is protected by the same treaty and it is reported that they are coming back in considerable numbers. But another species of sea otter found on the California coast is almost at the vanishing point. I am afraid the treaty came too late to save it. But it may recover. The fur seals on Guadaloupe Island apparently became extinct several years ago. There is not a good specimen of its skin in any museum in the world. The same is true of the sea cow. The last one was killed probably in 1868. So Steller's sea cow has gone to join the dodo and the great auk. These are merely a few examples of large marine mammals which have disappeared. I see no reason to believe that certain marine fishes are not

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in the same danger. The statement that has been made that man can not do anything to decrease or increase the supply of fish in the sea may well be questioned. It may be true of such fish as the herring, but the large marine fishes like the tuna will go like the elephant seal, the polar bear, the walrus, and Steller's sea cow. They are easily gotten at and easily exterminated. I would like to urge that the countries bordering the Pacific get together and make an international treaty for more adequate protection of these animals in imminent danger.

As to the fishes, I want to speak briefly regarding those of this particular region. I have been interested in the origin of the Hawaiian Fauna discussed by others. Just a few figures concerning Hawaiian fishes. First, it is interesting to know that the first fish ever collected near the Hawaiian Islands was obtained by Solander and Banks of Captain Cook's expedition. It was a beautiful Chaetodon now very well known. The specimen found its way into the Museum of Banks where it was described in 1782 by Broussonet as *Chaetodon longirostris*. When I read of this fact I felt a greater respect for the Cook expedition.

There were other expeditions following that of Cook in which other collections—about 30 or 40 specimens—were made. Dr. Gunther of the British Museum got a collection which he began to study but never completed. But it was the first great work on the fishes of Polynesia—and a very important work.

Considerably later Dr. Oliver P. Jenkins then of Depauw University, later Professor of Physiology in Stanford University conceived the idea of coming here and collecting fishes. In 1889 he organized an expedition and spent the summer here and made the first large and really valuable collection ever made about the Hawaiian Islands. He lists about 250 species, many of which were new and which he describes.

Then the Bureau of Fisheries in 1901 undertook the study of the fish fauna of the Hawaiian Islands, and made very large collections. The next year the Bureau sent the "*Albatross*" to study the deep sea fishes. The result of the work of 1901 was 440 species of shore fishes collected about these islands. Practically all of them were reef or shallow water

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species. There were fresh water fish found in all the streams in Polynesia.

Of these 440 odd species 232 are peculiar to the Hawaiian Islands; and that is important. One hundred and forty-three are common to Hawaii and Polynesia (by Polynesia I mean Samoa, Fiji, Tahiti, etc.) and there are only 53 species common to Hawaii and Japan; 34 are common to the Hawaiian Islands and the coast of Mexico, Central America and Panama. Thirty four is a small number and does not mean any relation whatever between the Hawaiian Islands and American Continent. These species of fishes are widespread and are found wherever there are suitable tropical waters. There appears to be no relation between the fish of Hawaii and Japan or between the coast of America or Alaska and Hawaii. There is a slight relation between these islands and the Galapagos—but it is so small that we could almost ignore it.

Each of the islands to the south and southwest of us has served as a center of influence from which the fish have spread. Supposing the fish to have spread from India, then each island would serve as a center of influence. The big break would be between the Hawaiian Islands and Samoa because the distance between those two is greater than between any two others in Polynesia. As a rule, I am disposed to think that shore fishes do not spread very readily or very widely. The fish which spread very rapidly and widely are the pelagic fish, which may be found anywhere where the temperature is suitable. Most of the fish of Polynesia are shore fish that stay close about home. They may be found in the same place, near a wreck perhaps, from year to year, and the offspring will remain in the same place as the parents. We should keep this in mind when discussing the question of the spread of fish by means of swimming or currents.

DISCUSSION

MR. BARTSCH: Are not the fish with pelagic eggs found very widely distributed?

MR. MOORE: Yes, some of them with long larval periods, for example the eels, the leptocephali of which are carried thousands of miles.

MR. MAYOR: The color of the fish in water is protective. The lighter colored belly of the fish makes him almost invisible under water. The same thing happens in an experiment I saw tried with a potato. It was visible from a long distance across the field when

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placed on top of the earth. But when the lower half was painted white it was lost to view almost immediately.

MR. MOORE: A very large number of those fish referred to by Dr. Mayor will be found to have pelagic eggs, but they have as a rule a comparatively short period of incubation so they do not have time to be carried far. Also the food of the adult and of the young is found at or near the bottom. When they have to descend any considerable distance to find bottom they find unsuitable and insufficient food and die.

MR. BARTSCH: An interesting point about deep sea fish is that they sometimes come to the surface at night to feed. I remember in the Philippines we caught fish at the surface at night that ordinarily are found at a great depth. In the day time we would often bring them up dead, but we picked them up at the surface at night active and frisky.

MR. EVERMANN: The fish that can do that are built on just the opposite plan from submarine vessels. The latter would be built strong and solid, the fish are very loose-jointed.

MR. FRASER: Dr. Evermann did not make the question of conservation of mammals serious enough. For a long time there were two whaling companies in British Columbia, last year a single one. They had been operating for many years. Years ago there were many humpback whales, but in two or three years there will not be one.

MR. EVERMANN: A point to consider is that we must have the life history of the marine mammals in order to know what to recommend for their conservation. The thing needed is an investigation in order to get a clear understanding of what must be done, if anything, to conserve and save the large marine mammals. We do not know enough about them. We can get some information about the whale from the stations but that never has been done so far as I know.

MR. CHILTON: In New Zealand the seals became so scarce as to make them unprofitable commercially. Consequently they were left alone and now they are coming back. Now they are protected. The same thing may happen with the whales.

MR. BARTSCH: Is it not a fact that they are using every bit of the whale?

MR. EVERMANN: Yes. The meat was sold for food during the war. Since the war the oil is extracted from the flesh, all the glycerine is gotten out, then the flesh, bones, viscera, and blood are made into fertilizer.

MR. FRASER: It is only on condition that everything is used that the business may be carried on.

MR. BRYAN: There is a great deal of whaling carried on by Norwegian whalers on the South American coast near Chili. It occurred to me that if the Government of Chili would deny the right of landing to try out and to operate the whaling stations, they could control the number of whales taken. If the Norway whalers were not allowed concessions on the South American coast they would have to make a long run home. The Atlantic countries might not fall in very readily with an agreement made between the Pacific governments for the conservation of its marine life.

MR. MOORE: The Norwegian whaling in South America is the result of such a law as you suggest. In Norway it drove the whalers away from their own country to the southern seas.

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MR. EVERMANN: That same law was in a measure successful on the Alaska coast. But floating rendering works were established so that they caught the whales at sea and rendered them on board as in the old days.

MR. KISHINOUYE: In Japan the government restricts the number of whaling vessels to about 30 and no more vessels are allowed to catch whales.

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BIOLOGICAL STATIONS AND SIMILAR INSTITUTIONS IN THE PACIFIC REGION

[NOTE: Expected contributions from J. Allan Thomson, Director of Dominion Museum, Wellington, New Zealand, and from K. Kishinouye, Professor of Fisheries, Tokyo Imperial University, Japan, had not been received at the date of publication.]

THE PHILIPPINE BUREAU OF SCIENCE

By ELMER D. MERRILL, DIRECTOR

The Bureau of Science, Manila, P. I., is wholly supported by the Philippine Government from local revenues; the appropriations for the support are made annually. It was established in 1901 under the name Bureau of Government Laboratories, becoming the Bureau of Science in 1906. The prime object in the establishment of the institution was to centralize scientific effort, so far as the Government was concerned, in order to avoid duplication in various Government units, of expensive technical personnel and equipment.

The institution is a very comprehensive one as may be seen from an outline of the work given below. Pure science, as such, is but a small part of the function of the institution as from the very nature of conditions in the Philippines the practical application of science must be stressed. The organization calls for all routine chemical work for the various units, including that necessary in connection with the enforcement of the pure food and drug laws, as well as original investigations of a chemical nature on Philippine problems. Provision is also made for chemical work for the general public, commercial units, etc. The institution does all work in connection with the standardization of weights and measures for the Philippines; the testing of all materials used in construction, such as cement, timber and steel; the manufacture of tikitiki extract for the cure of beriberi; the manufacture of all types of vaccines, serums and other biologic products; the administration of the Pasteur treatment; routine microscopic examination of all material submitted by the Bureau of Health in the detection and control of contagious diseases; and the investigation of diseases of a bacteriological nature as well as those caused by internal animal parasites. It maintains completely equipped laboratories for the work

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enumerated and also separate departments with the necessary laboratories, for geology and mining including assaying, botany, plant pathology, icthyology, including the maintenance of a large modern public aquarium, entomology, and orinthology. The Bureau of Science is the custodian of the governmental collection of natural history material, the herbarium containing upwards of 200,000 mounted sheets, while collections in icthyology, entomology, ornithology, and geology are relatively as extensive. The central scientific library of the Philippine Government is a part of the Bureau of Science, containing about 70,000 volumes on the sciences in general, while about 1100 technical periodicals are currently received. The Bureau publishes the Philippine Journal of Science, now in the 18th year, over 50 individual volumes having been issued, and also publishes a special series of monographs consisting of works too extensive for inclusion in a technical periodical. A completely equipped photographic laboratory is also maintained, now containing over 20,000 negatives. The Bureau maintains its own power plant, supplying electric power, steam, compressed air and vacuum to all laboratories.

It has been the constant policy of the Bureau of Science to cooperate to the greatest possible extent, not only with other governmental units in the Philippines but with scientific institutions all over the world. Requests for natural history material are complied with so far as the technical personnel available can meet the demands and so far as material is available. Visiting scientists are always welcome, and will be granted the full facilities of the institutions, laboratory space and equipment so far as it is available.

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AUSTRALIAN MUSEUM, SYDNEY, NEW SOUTH WALES

By Charles Hedley, Curator

There is not now a single marine zoological station in Australia. About forty years ago a small one was formed in Sydney Harbor by Michlohou Maclay, a Russian zoologist. The site of this was afterwards resumed by the state government. Money paid as compensation for that resumption is in the hands of trustees and will be available for opening a station near Sydney.

Several Australian states have purchased trawlers and operated fishing as a public business. It has been represented that marine biological stations would be proper adjuncts to State fishing departments.

The lucrative pearl shell and bêche de mer fisheries have especial need of investigation. Until a more intimate knowledge of the life history is obtained of these animals and their associates these industries cannot be adequately organized and controlled. Establishment of such stations is being advocated by the Australian Bureau of Science and Industry.

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THE CANTERBURY COLLEGE MOUNTAIN BIOLOGICAL STATION

By Charles Chilton, Professor of Biology

One biological station at Cass, New Zealand, was established in 1913 primarily for the instruction in Zoology and Botany of the students of Canterbury College. It is situated at an elevation of about 2000 feet above sea-level and among mountains rising to a height of 6000 feet. The surrounding district is rich in indigenous vegetation and supplies examples of subalpine tussock grass land, mountain forests, scrubland, river bed and shingle-slip formations, swamp and fresh water streams. It is easily reached by rail from Christchurch and the building offers comfortable accommodations for students and workers. The station is within easy reach of the great natural forests of Westland and can be used for forestry instruction on the problems presented by the mountain pastures.

Though primarily intended for class instruction the station has already been used by graduates and workers from elsewhere for the purpose of research and the results have been published in the Transactions of the New Zealand Institute. The Station is under the control of the Professor of Biology of Canterbury College who will be glad to exchange publications and specimens with similar institutions.

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THE PORTOBELLO MARINE FISH HATCHERY AND BIOLOGICAL STATION, OTAGO HARBOR, NEW ZEALAND

By W. J. Phillipps, Dominion Museum, Wellington, N. Z.

(Presented at the request of the Committee on Program.)

In a paper read before the Otago Institute on October 8, 1895, entitled "On New Zealand Fisheries and the desirability of introducing new species of Sea-fish," Mr. G. M. Thomson suggested that, before any further legislation was proceeded with in connection with the fisheries of the colony, it was necessary that a marine biological station be established where systematic observation of the habits and life-histories of the local species of fish might be carried out. The apparent feasibility of the suggestion commended itself to the Otago Institute and in the summer of 1896, a committee was appointed to consider the matter and to examine and report on the Otago harbor and its neighborhood in regard to its suitability for such an establishment. Following a favorable report by the committee and the Council of the Otago Institute and the Committee of the Otago Acclimatization Society each voted the sum of £250, conditionally to Government granting £500 for the work, and undertaking to carry on the station for a few years. In 1899, Government approval of the project was obtained and early in 1900 the site for the station was selected. After two years of negotiation and delay Government agreed to allow the work to proceed on the understanding that the cost of establishing the hatchery in working order should not exceed £1100, and the annual working expenses not exceed £250. An honorary advisory board was set up consisting of one member from the Otago Institute, one member from the Otago Acclimatization Society, the Collector of Customs, the Chief Surveyor, and the Superintendent of Mercantile Marine. In 1904, the Marine Fish Hatchery and Biological Station was formally opened and began its work under the curatorship of Mr. T. Anderton, followed in turn by Mr. W. Adams and Mr. S. Broadley, the officer now in charge.

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The equipment of the station consists of eight tanks, a laboratory building and a motor launch specially built for fishery investigation.

Much valuable information is being collected yearly on the various fishes, their seasons of abundance, and wholesale prices realized in the markets. A list of the boats and of their class operating from different ports is also kept as a check on the statistical tables.

In regard to the introduction of food fishes advice obtained from England and the United States indicated that though success might not be anticipated in the introduction of ova which might be hatched on arrival, there was a possibility of successfully introducing adult or half-grown fishes. The attempt to introduce herring was unsuccessful but live turbot, lobsters, and crabs were brought in.

About three hundred of the turbot (*Rhombus maximus*) were successfully introduced. After remaining in the hatchery and being fed for a period of over three years, 128 were liberated at a suitable locality at midnight on May 19, 1916. The remaining stock of 54 fishes were retained in the hatchery. Some were at this time as much as 22 inches in length; but up to the present it has not been possible to obtain one in spawning condition. On September 1, 1917, 42 large turbot were liberated in about 15 fathoms of water; but have noc been since recorded.

Five shipments of the European lobster (*Homarus vulgaris*) were made and in all 39 males and the same number of females have arrived. A large number of eggs have been successfully hatched and larvae liberated. A total of 10 male and 6 female examples of the European edible crab (*Cancer pagurus*) were introduced up to 1911. Most have since died; but a number of eggs were successfully hatched and large plants of fry made on four separate occasions. Later in 1913, some 43 crabs were successfully landed (out of 50 shipped). Apart from eight which were retained in the hatchery and a number which died these were liberated soon after arrival.

As outlined by the Hon. G. M. Thomson, at present honorary director of the Portobello Marine Hatchery and Biological Station and who is mainly responsible for its es-

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tablishment, the aims and objects may be summarized as follows:

1. To ascertain a thorough knowledge of the hatchery environment including such features as the salinity of the water, temperature, and tides.

2. To serve as a base for receiving such fishes or crustacea as it may be advisable to introduce.

3. To acquire an exact knowledge of the migration, food, rate of growth, spawning seasons of our local fishes in order that we may be in a position to conserve the supply of local fishes for future generations without undue restrictions on the fishing industry.

4. To serve as a base for those desirous of pursuing a purely scientific study of marine biology.

5. To place on record the results of experiments and investigations and the conclusions and deductions which may be drawn from these observations.

The work which has already been accomplished under difficulties of finance and unnecessary restrictions can only be regarded as preliminary; but the vast economic possibilities of the future arising from further successful attempts to acclimatize profitable marine fauna from the Northern Hemisphere will be immediately apparent when we consider the small amount which has already been attempted and its relative success.

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UNITED STATES NATIONAL MUSEUM

By Paul Bartsch, Curator Division Marine Vertebrates

The United States National Museum, while it maintains no stations on or in the Pacific, nor a vessel for exploration, has nevertheless contributed an enormous amount of information on the fauna and the flora of this region, as evidenced by its publications.

The National Museum is the recipient of the material secured by all the Government surveys and explorations. For example, here reposes all the material gathered through the many years of splendid efforts of the United States Bureau of Fisheries' steamer *Albatross*. The National Museum at the present time contains the largest collection of mollusks of any institution in the world. From the Pacific, we have the most perfect series from its eastern shores. Not only that, we have the splendid collection made by the *Albatross* in the northern waters and along the coast of Japan, and from this region, also, the fine material obtained by Prof. Edward S. Morse while he was stationed at the University of Tokyo in the early '70s, and more recently the collection of Mr. Y. Hirase obtained by him and his co-workers during a lifetime of effort. From the Philippines, the Celebic, Flores and Banda seas we have the splendid material secured by the *Albatross* during its several years' explorations in those waters, and from the South Seas in general that material which the *Albatross* secured during its cruises under the late Dr. Agassiz. The Hawaiian group is represented by material obtained by the *Albatross*, and more recently by the donation of the Thaanum collection sent in by that indefatigable collector, Mr. D. Thaanum, which more than anything heretofore makes known to us the shallow water faunas of these islands. To these should be added material obtained by purchase and exchange from various sources, so that with the exception of the Australian region, from which also the early exploring expeditions have given us some collections, we are fairly equipped with the Pacific elements of these faunas.

Now the policy of the National Museum has ever been to help any institution or individual in its investigations, either by the loan of material or by furnishing study place

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in our own Institution for students where they may pursue comparative studies, or by actually having various members of the staff report upon material sent in for examination and report. I am sure there is not a single institution represented here which, if we were to call upon it, would not be able to say that the National Museum has always cooperated in the fullest measure with the members of its staff, in order to make the widest use of its collections, and I may say in behalf of our Institution that we shall always be glad to cooperate.

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THE BUREAU OF FISHERIES

BY H. F. MOORE, DEPUTY COMMISSIONER

I am surprised to be called on to speak at this symposium on biological stations of the Pacific, as the Bureau of Fisheries has no such station. A number of years ago we wished to establish one in the Puget Sound region and a bill making an appropriation for the purpose was introduced in Congress but failed of passage. That was before the establishment of stations at Nanaimo, Friday Harbor and at Port Renfrew on Vancouver Island, which have been here described by their respective directors. If the same proposal were to be made now I doubt if I should favor it as I believe that the interests of science and the fisheries can be advanced better by strengthening the existing institutions in that region rather than by increasing their number.

While we have no station on the Pacific Coast we have maintained a floating laboratory for many years, the steamer *Albatross*. This was the first vessel designed and built for oceanographic investigation her predecessors being warships or other vessels temporarily refitted for exploration and research. The *Albatross* is not of the exact type which would be built to-day but she has been refitted recently and provided with modern gear, so that notwithstanding 35 years of service she is apparently good for many more years of work in her field. She is now on the Atlantic coast where she will be engaged for two years, if all goes well, on a project of research off the south Atlantic coast of the United States and in the Gulf of Mexico and Caribbean Sea. This work will in some part supplement the investigations of the International Council for the Exploration of the Sea which are being extended as far as Bermuda. When this duty is accomplished I hope that she may be returned to the Pacific to take up investigations on the northwest coast of the United States and thence northwest to the Aleutian Islands, in cooperation with the biological stations in that region and such other agencies as may be available for a systematic study of the biological and other factors affecting the fisheries. With the biological stations conducting researches in the coastal areas and the *Albatross* at sea, I believe something of both scientific and

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economic value can be accomplished in a field which sadly needs attention.

In conclusion I wish to say that the Bureau of Fisheries still endeavors to maintain the traditions and the policy of Professor Baird. It is organized for service and is ready to assist so far as its means will permit in any work which will further the advancement of knowledge concerning the sea.

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BERNICE P. BISHOP MUSEUM

By Herbert E. Gregory, Director

The history, scope and policy of Bishop Muesum is outlined by Mr. Albert F. Judd in his Address of Welcome printed in this volume.

The funds of the institution are expended on two closely related activities: the gathering of materials and investigation. The exhibition halls and laboratories contain large collections from Polynesia and to a less extent from other Pacific areas. In order of value for research work, the collections in ethnology rank first, followed in turn by conchology, botany, entomology, marine zoology and ornithology. Through gifts, purchase and field expeditions the collections for study are rapidly increasing in amount and value.

The investigation of problems in Pacific ethnology and natural history absorbs the larger part of the Muesum funds and the staff is organized primarily with this purpose in view. For example during the present year, in addition to laboratory investigations, four parties are at work in different parts of the Pacific following a program designed to shed light on the origin of the Polynesian race and the history of plant life in the Pacific. Through the Biological Laboratory the museum is cooperating with the University of Hawaii in the study of fish and littoral fauna of Oahu and other islands. The collections, laboratories and library, particularly strong in works relating to the Pacific, are available for use by properly qualified students. The publications of the museum: Memoirs, 7 volumes; Occasional Papers, 7 volumes; Miscellaneous Publications, 8 volumes, are distributed to institutions and to professional workers.

HAWAIIAN SUGAR PLANTERS EXPERIMENT STATION

See statement by H. P. Agee, Director, printed in this volume with Addresses of Welcome.

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BIOLOGICAL LABORATORY, UNIVERSITY OF HAWAII

By C. H. Edmondson, Professor of Zoology

The biological laboratory for research of the University of Hawaii is now being erected through the generosity of the Cooke estate. It will be ready for occupancy in September of this year. This laboratory will be open to investigators, local or visiting, for the pursuance of research in biology during the entire year and every possible facility will be placed at their disposal.

Local problems in biology are numerous. Marine life about the islands naturally resolves itself into three zones, the life of the shore, the life of the reef and the life of the open sea. Much of the biology of the beach and of the reef can be studied very thoroughly without much equipment and by working from the shore. Work upon the open sea, however, cannot be carried on without the aid of a boat of some size, with which the laboratory is not yet equipped. It is my belief, however, that satisfactory arrangements can be made for the use of boats now in Honolulu harbor if it is desirable to carry on surface work outside the reef or dredging operations at comparatively shollow depths.

We hope to make the biological laboratory at Waikiki not only accessible to local workers but a place to which we can invite specialists in various fields of biology for work upon special problems. Biologists passing through Honolulu and wishing to stop and work for a time may have the privilege of carrying on their activities here. The University of Hawaii hopes also, by the better equipment and facilities offered by the completion of the laboratory, to stimulate interest in biology among her own students and encourage some, if possible, to continue in research.

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THE PACIFIC COAST BIOLOGICAL STATION

BY C. M. FRASER, DIRECTOR

The Pacific coast Station at Nanaimo, B. C., under the control of the Biological Board of Canada, has been in operation since 1908. It is situated on the shore of Departure Bay, on the east coast of Vancouver Island, 40 miles across the strait of Georgia from the city of Vancouver and 75 miles northwest of Victoria.

The Biological Board, consisting of a representative of the Federal Department of Fisheries and several university representatives, is not responsible to any government department but is advisory to the Department of Fisheries.

The station is maintained solely for research work. The accommodations are somewhat limited but after investigators doing work directly for the Board are accommodated, the facilities of the Station are available for any other workers until that limit is reached. The Station is open throughout the year and except during a part of the summer there is always plenty of room.

As the Biological Board is closely associated with the Department of Fisheries, investigation of problems relating to the life history of food fishes has received much attention and will continue to do so. For such work the location is very suitable since there is easy access to plenty of material in nearly all species of economical value caught along the coast of the province.

Next in importance, as it is the basis of all other work, is the biological survey, which is gradually being extended in scope. Many of the animal groups have been worked up at the station or at other points where specialists were willing to undertake the work. Besides these many ecological, morphological, bacteriological, biochemical and physical problems have been attacked. As there are numerous islands with variety in coast line separated by channels of varying width and strength of current, there is plenty of chance to study the ecology of numerous species under much varied conditions. This is particularly true of inter-tidal and shallow water forms since there is a variation of 16 to 18 feet at spring tides, with a tide having a velocity up to 12 knots an hour.

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The constantly changing amount of fresh water poured into the strait of Georgia by the large rivers makes the study of the effect of variation in salinity a complex question, particularly since with this may be coupled extensive variations in temperature of the surface water at least. Since the waters are well protected, almost inland waters, work can be carried on without danger or difficulty throughout the year.

Open ocean conditions do not prevail, hence the Station is not suitably situated for any work where such conditions are necessary. The equipment consists of a 40-foot and an 18-foot motor boat, several row boats, dredges, nets, water-bottle, etc., with considerable laboratory equipment for biological, chemical and physical work. The library consists of upwards of one thousand volumes besides separates.

If it were not for the assistance of university men, who can spend a little time in the summer, the question of workers would be rather acute; as it is, more full-time men are required. Possibly these could be obtained if the funds were forthcoming. The last six years have been lean years but better times are approaching.

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THE MINNESOTA SEASIDE STATION

By Josephine E. Tilden, Professor of Biology

The Minnesota Seaside Station was established in 1901 at Port Renfrew, Vancouver Island, British Columbia. For seven years it was successfully maintained by certain members of the Botanical Department of the University of Minnesota. Parties of 25 to 40 investigators attended this summer laboratory each year. During the seven years 200 research workers in botany, zoology and geology from the United States, Canada and Japan were in attendance at this station in the wilds of Vancouver Island. It may be stated that this locality has been pronounced by experienced European travelers as one of the best in the world for biological research.

The Station is situated on the southwestern shore of Vancouver Island sixty miles west of Victoria, opposite Cape Flattery. The shores are exposed to the full force of the open waters of the Pacific. There are four different types of shore formation: slate, shale, sandstone and limestone. Each is found to support its own particular fauna and flora. Potholes of all shapes and sizes are found in the rocky shelf exposed at low tide. These afford a marvelous display of plant and animal forms and opportunity for a study of their life histories.

Because of the fact that the temperature of the air never reaches the freezing point there is an excellent opportunity of study of all-the-year-round problems. Bright sunny days are uncommon as foggy weather predominates.

During the years in which the station was regularly maintained about fifty botanical papers were published. The organ of publication of this station is "Postelsia," the Yearbook of the Minnesota Seaside Station. Two volumes have so far been published.

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THE PUGET SOUND BIOLOGICAL STATION

By T. C. Frye, Director

The Puget Sound Biological Station of the University of Washington is located at Friday Harbor, Washington. Work was begun in 1904, but little attempt was made at research. The time was mostly devoted to classes and to collecting, with a view to studying geographical distribution. No buildings were erected until 1910, and equipment was returned to the university at the close of each summer session. Classes were held in rented canneries and other buildings. The chief aim in the class work was to produce better teachers of biology.

Beginning with 1914, research was made one of the chief aims of the Station. With this in view a library was begun, which has now reached about 750 volumes. With the same end in view, the publication of a series known as "Publications of the Puget Sound Biological Station" was begun in 1915. This series has reached nearly two volumes at present, and will likely increase annually for some time. It consists of 52 articles, about half botany and half zoology.

Its buildings have a floor space of about 4700 sq. ft. devoted to zoology, about 1500 sq. ft. devoted to botany and about 1500 sq. ft. devoted to mess, social gatherings and storage. Usual chemicals and glassware are at hand, as are also row boats. A shrimp steamer is rented for trawling purposes.

The chief lines of work have been ecological and physiological, with a view to explaining the distribution of plants and animals on the basis of their reactions to physical and chemical factors. This has grown out of work in geographical distribution.

The station is open for work only about 3 months during 6 weeks of which class work is given. The work of the Station must therefore be largely what those who come there are prepared to do. Work along almost all lines is done. Hard rocks and the swift tidal currents through the channels between the islands favor a rich fauna and flora, while tides of twelve or thirteen feet make the shore material easily available.

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The attendance this year reached about 65, of whom about 10 per cent were under-graduates, and about 20 per cent had doctor's degrees.

The Station is supported almost wholly by the University of Washington, and at present costs the State about $4000 a year, in addition to the funds derived through a fee of $13 a person and through the sale of biological material. The last two items bring in about $1500 more, making a total of about $5500.

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HOPKINS SEASIDE BIOLOGICAL STATION AND THE STEINHART AQUARIUM OF THE CALIFORNIA ACADEMY OF SCIENCES

BY BARTON W. EVERMANN

I cannot speak officially for the Hopkins Biological Station of Stanford University, but as there is no one present representing that station, I shall make a brief statement regarding it.

This station was established soon after the founding of Stanford University and is the oldest biological station on the Pacific Coast. It was established by funds supplied by Mr. Timothy Hopkins, one of the trustees of Stanford University, who has also supplied from time to time the funds necessary for its equipment and maintenance. The station is located at Pacific Grove on Monterey Bay.

It has largely functioned as an adjunct to the departments of zoölogy and botany, of Stanford University, and as a place where investigators from anywhere might come and study problems in which they are interested. The fauna and flora of Monterey Bay are so rich in species and individuals including numerous forms of unusual or special interest, that many investigators have availed themselves of the exceptional facilities there afforded.

Recently a new laboratory building has been erected. This building was carefully planned as to internal arrangement and architectural appearance. The equipment has been materially improved and provision made for more adequate funds for maintenance. Dr. Walter K. Fisher, of the Department of Zoölogy, Stanford University, and curator, Department of Invertebrate Zoölogy in the Museum of the California Academy of Sciences, is the permanent Director, and the station is open throughout the year. I am sure that Director Fisher and the other biologists at Stanford University will cordially coöperate with the biologists connected with the biological stations in the Pacific area.

The facilities of the California Academy of Sciences for biological research consist of the laboratories of the various departments, particularly those of botany, entomology, herpetology, invertebrate paleontology and conchology, invertebrate zoölogy, mammalogy, and ornithology and the library. Several of the departments of the museum are rich in collections from the Pacific and the countries bordering thereon. This is particularly true in entomology, ornithology, herpetology and conch-

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ology. The facilities of these departments are fairly good for the study of Pacific material in these lines.

Recently the Academy received a gift of $250,000 with which to build and equip an aquarium. The gift was made by Mr. Ignatz Steinhart, a public-spirited citizen of San Francisco, recently deceased. By the terms of the will, the aquarium will be located in Golden Gate Park, adjoining the Museum of the Academy of Sciences, and the management will be under the Academy of Sciences.

An amendment to the charter of San Francisco was recently adopted which directs the Board of Supervisors of the City of San Francisco to appropriate and pay over to the Academy of Sciences, annually, *not less* than $20,000 for the maintenance of the Steinhart Aquarium. This sum will probably be inadequate, but if the Aquarium proves the success we hope to make it, it is believed public sentiment will support the Supervisors in increasing the allotment.

The aquarium will have, as a part of its equipment, laboratory facilities for the study of aquatic life; indeed there is a very strong probability that another public-spirited citizen will supply a special fund for adequately equipping and endowing a thoroughly modern up-to-date biological laboratory in connection with the Steinhart Aquarium. When this is done the Academy of Sciences through its various departments, library and aquarium will, it is believed, be in a position to render efficient coöperation with investigators interested in Pacific problems.

Besides these facilities for coöperation offered by the California Academy of Sciences, there are the library and collections of the University of California, and the great ichthyological collections and library of Stanford University. And I must not neglect to mention the California Fish and Game Commission, which, with its various patrol boats, especially the *Albacore*, can and will no doubt be glad to assist materially in work along the California coast.

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THE SCRIPPS INSTITUTION FOR BIOLOGICAL RESEARCH

By George F. McEwen, Oceanographer

ABSTRACT

In the absence of Dr. Ritter, Director, this outline of the history and scope of Scripps Institution is presented.

When, in 1891, Dr. Ritter was called to the newly formed department of biology of the University of California, he recognized that the Pacific waters along the west coast of North America constituted an almost virgin field for scientific investigation. He soon found, however, that the San Francisco Bay region did not contain many of the plants and animals that are most characteristic of the open ocean; and in 1892 a temporary laboratory for marine work was erected at Pacific Grove, from which station during the summer of 1892, and succeeding seasons, experiments were carried on as far south as San Diego. From 1896 to 1901 no seaside laboratory work was maintained, but collecting trips were made along the coast from San Diego to Alaska by various members of the biological department. The experience thus gained indicated that San Pedro was an especially favorable spot from which to carry on marine studies, and accordingly a seaside laboratory was established there, and dredging, trawling, collecting and also hydrographic work was done during 1901 and 1902.

During the following year better accommodations were found at Coronado and a local organization was formed and resident naturalists employed for the purpose of making a "Biological and Geographical Survey of the Waters of the Pacific Adjacent to the Coast of Southern California." The village of La Jolla, about twenty miles north of Coronado, was the home of the enterprise from 1905 to 1909. The present home is on the coast two miles north of La Jolla, a location determined by favorable conditions for collecting, abundance of pure ocean water and a large area uncontaminated by industrial plants of cities. On August 6, 1916, occurred the dedication of the latest additions to the present plant, consisting of the public aquarium, a concrete pier, two large concrete buildings for laboratories, library, museum and administration. In 1912 the local organization turned over the institution to the University of California and the name was changed from The Marine Biological Asso-

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ciation of San Diego to the Scripps Institution of Biological Research of the University of California.

Financial support for the earlier activities was in part from the University of California and in part from private subscriptions. From 1905 to 1912 funds for extensive field work were provided by Miss Ellen Scripp and Mr. E. W. Scripp. Since 1912, when the institution was taken over by the University of California the public has contributed largely to its support in addition to the regular income of the Scripp endowment and from the small funds given from time to time for special purposes.

When plans for the investigation of the biology of the waters of the Pacific were formed, the need of the combined efforts of a number of individuals of varying qualifications was recognized, and particularly since 1905 provision has been made mainly for team work directed toward definite ends, and the solution of certain biological problems of the sea, has received a large share of attention. Although a salaried staff have devoted all their time to problems chosen by the institution, other investigators wishing to work on problems of their own, have always been welcome, and many have taken advantage of this opportunity. The resources of the institution are available also for investigators devoting their attention to land animals. The institution's program of marine biology and hydrography has been based largely on problems suggested by the general question of the seasonal distribution of each species of organisms, its horizontal and vertical distribution, its food and reproduction, migration and relation to the environmental factors, or physical and chemical conditions of the water. In other words, the major work of the institution has been in the field of what is now generally known as Ecology. These intensive investigations have been limited to a few groups of the most abundant plankton, the Chaetognaths, Copepods, Ascidians, Diatoms and Dinoflagellates. Such problems have been attacked mainly by means of quantitative field collections and observations, where control over the conditions was impossible. This field method has been supplemented by laboratory experiments, and it is recognized that both methods have their place in the attempt to answer such questions.

The need of giving special attention to the environment, that is, to the physical and chemical conditions in the sea, led to the addition of a physicist to the staff in 1908. Since then con-

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siderable attention has been directed not only to making observations relative to the water, but also to a few selected problems of physical oceanography suggested by these observations. Certain results of these studies have proved of value in interpreting the biological data and have clearly shown the close relation between ocean and atmospheric phenomena. Attention has been given also to quantitative methods of dealing with the data, with a view to getting at the deeper significance of the facts observed.

The work at sea has not been as continuous as the problems need, either from the standpoint of biology or physical oceanography—a situation which has been remedied to a certain extent, during the last five years, by regular daily collections and observations from the institution's pier and by daily collections by coöperative observers at a series of fixed positions along the coast from San Diego to Pacific Grove.

Although the Scripps Institution has been engaged primarily in research in pure science, it has coöperated for ten years with the bureau of soils in the study of kelp and to a limited extent with the bureau of fisheries, and with the State Fish and Game Commission.

Formal instruction is not carried on by the Scripps Institution, but opportunities are offered to graduate students for advanced work pertaining to the fields of investigation in which the institution is engaged and in connection with the work of the museum and aquarium, a supply department is operated for furnishing educational institutions with marine animals from the Pacific coast.

Further information regarding the Scripps Institution is presented in various published papers, especially in one by the director, entitled "The Marine Biological Station of San Diego, Its History, Present Condition, Achievements and Aims."

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SUGGESTIONS FOR BIOLOGICAL WORK IN THE PACIFIC

THE IMPORTANCE OF SYSTEMATIC EXPLORATION OF THE LAND FAUNA OF ISLANDS IN THE PACIFIC

Based on data collected by C. W. Richmond and arranged by T. S Palmer, with notes by R. C. Oberholser and Leonard Stejneger.

By E. W. Nelson, Chief, Bureau of Biological Survey, Department of Agriculture, Washington, D. C.

INTRODUCTION

Since the days of Darwin's investigations in the Galapagos Islands interest has steadily increased in the many problems relating to the life history and distribution of the higher vertebrates on the islands in the Pacific Ocean. Notwithstanding this, comparatively few of these islands have been thoroughly examined; in fact, aside from the Galapagos and Hawaiian islands and some collecting on Samoa and the Fiji islands, practically none of the small groups have been carefully studied. Birds naturally form the most interesting of the terrestrial vertebrates. Indigenous mammals are comparatively few and the number of species of reptilia and amphibians is relatively small. Even in the case of birds, our knowledge at this late date is extremely fragmentary and based on casual collecting rather than systematic exploration. On some of the more important expeditions zoölogical collecting was merely incidental to other work and the labors of naturalists were limited to a few hours on shore. The main object of Capt. Cook's voyages was not zoölogical collecting; the voyage of the *Blonde* was undertaken to convey home from England the remains of the deceased king of the Sandwich Islands; and the Wilkes Exploring Expedition was so occupied with other matters that the naturalists were often handicapped in their work and frequently had but a few hours to spend on shore on some of the islands, while others were passed untouched.

When these facts are recalled it is not surprising that even on the islands which have been most thoroughly worked, new species are still found. In fact so little is known of the zoölogy of the region that information regarding even the best explored of the larger islands is today in much the same condition as that

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of the Hawaiian islands thirty years ago when the Hawaiian group was regarded as fairly well known. More careful search since that date has brought to light at least ten new genera of birds, the last (Dysomorodrepanis) described in 1919. With one exception these are all land birds and are so distinct as to cause considerable discussion as to their family position. The larger islands in the Samoan group, the Fijis, and the Carolines may have similar novelties. On the other hand practically nothing is known of the birds of Easter Island, although it was visited by Capt. Cook a century and a half ago, and subsequently a small land bird was reported as present. The family to which this bird belongs is still unknown. It so happened that at the time of Capt. Cook's visit the naturalists, J. R. and Georg A. Forster, were ill, otherwise more definite knowledge might have been obtained regarding this species. In recent years the island has been utilized as a range for cattle, horses, and sheep and in 1886 supported about eighteen thousand sheep. A South American tinamou and probably other birds have been introduced, but from a distributional point of view the identity of the native land bird is of peculiar interest in view of the fact that the nearest island, Pitcairn, from which it might have been derived, is several hundred miles distant.

Even of some species which have been described existing knowledge is extremely vague and slight; no specimens have been received and the species are known only from drawings based upon field sketches. Aside from the Hawaiian birds practically nothing has been recorded concerning the anatomy of the great majority of the known species. If the results of Gadow's investigation of a small collection of Hawaiian birds in alcohol may be taken as a criterion, results of the highest importance may be looked for when the anatomy of other insular forms is better known.

Nowhere in the world perhaps are terrestrial forms of vertebrate life subject to greater dangers and vicissitudes than those in the isolated colonies on the Pacific islands. As mentioned further on, practically all the destructive agencies of nature, including fire, tidal waves, hurricanes, and the inevitable destruction due to occupation by man, such as deforestation, cultivation of the land, fire-arms, and the introduction of new enemies in the form of domesticated and wild animals and birds, are hastening the extermination of many species. With settlement of the islands

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have come also some of the worst pests from other countries such as the mongoose, rats, mice, and cats.

While much progress has been made in investigating problems in oceanography and vulcanology, and in studying the formation of coral islands and the wealth of marine life of the Pacific, and much still remains to be done in all of these subjects, strange to say comparatively little has been attempted in the direction of systematic exploration of the highly specialized and interesting land faunas. In the case of a number of species of birds there are no specimens in museums—and never have been any—since they are known only from drawings and descriptions. If the work of investigating the fauna of the islands is not soon undertaken, many of the most interesting forms will have vanished before any adequate information concerning their life history or even the bare fact of their occurrence is recorded. The presence of rats and mice and certain birds on some of the islands indicate former visits by man and careful study of all such cases may throw light on the distribution of the native races and add to our knowledge of some of the aborigines of Polynesia.

THE REGION UNDER CONSIDERATION

The wide expanse of the Pacific ocean is dotted with many islands and reefs, chiefly volcanic in origin or of coral formation, scattered over an area representing nearly one-fifth of the surface of the earth. Exclusive of continental islands, the area under consideration includes in broad terms the North and South Pacific from the Aleutian Islands to New Zealand and from the coast to America to the Philippines. It includes about 85 degrees of latitude from 50 degrees North to 35 degrees South, and 145 degrees of longitude, from 80 degrees West to 135 degrees East. It comprises the Hawaiian islands in the north, Juan Fernandez in the southeast and the Kermadec Islands, New Hebrides, New Caledonia, Solomon, and Marianne islands in the west, but does not include Japan, the Philippines, Celebes, New Guinea, Australia, or New Zealand. Within this area are hundreds of islands, some covered with dense vegetation and others bare reefs or sand spits. The majority are of great interest on account of the peculiar forms of life which occur on them, and because of the many problems involved in the distribution of species. Of birds the number of known species is probably not less than five hundred and of mammals the number now

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known is about fifty. These mammals are chiefly bats, rats, mice and seals but include several genera and a number of species peculiar to the islands. Many of the birds are rare and local, some of them are scarcely known and a few of them are now extinct. Among the number are some that are peculiar to one or more islands, and that represent genera not found elsewhere in the world.

There is no question that among the reptiles of Polynesia, few as the species are, many new ones yet remain to be discovered not only in the unexplored islands but even in those commonly visited by collectors. Among the lizards the most numerous families are those of the skinks and the geckos. Their distribution in Polynesia is very interesting and often puzzling, but more reliable material may solve some of the puzzles and a study of their geography may throw light upon the question of a former distribution of man in this part of the world. A boa-like genus of snakes Enygrus, the nearest alleged relations of which live in tropical America and Madagascar, seems to have its headquarters in the Solomon islands, where three out of its four species are said to occur. One of these species is supposed to inhabit New Britain, the New Hebrides, and the Loyalty Islands, as well as Rotuma and Samoa, while another is known outside the Solomons only from Fiji and Tonga. The enormous Iguanoid family of lizards, is with three alleged exceptions, confined to America; two genera occur in Madagascar and one genus with a single species is reported in the Fiji and Tonga islands.

Among Batrachians the occurrence of a frog of the genus Cornufer in the Fijis and its relationship with species of the same genus in the Philippines and New Guinea stand in great need of investigation.

EARLY EXPLORATIONS

Explorations of the islands in the Pacific date back almost exactly 400 years to the discovery of the Philippines and the Mariannes by Magellan in 1521. Other 16th century discoveries of importance in this connection are those of the Carolines by Vasco da Rocha in 1527, the Marshall Islands by Alvaro de Saavedra in 1529, the Pelews by Villalobos in 1543, Hawaii by Gaetano in 1555, the Solomon Islands by Mendaña in 1567 and the Marquesas by the same explorer in 1595.

The explorations in the 17th century resulted in the discovery of the New Hebrides, Society Islands and Tuamotus by

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Quiros in 1606 and the Fiji and Tonga islands by Tasman in 1643.

The 18th century brought to the charts the additions of the Gilbert Islands, discovered by Byron in 1765, Pitcairn by Carteret, and Tahiti by Wallis, both in 1767, Samoa by Bougainville in 1768, the Austral, the Hervey or Cook Islands and New Caledonia, all by Cook in 1769, 1773, and 1774, respectively, and the Loyalty Islands by Butler in 1800-1803. Thus by the beginning of the 19th century most of the more important islands had been discovered, named, and charted.

PECULIAR GENERA AND SPECIES

An important part of the terrestrial mammals, birds, and reptiles, consists of species that are peculiar to the region. Among the mammals are three genera of fruit bats, Melonycteris, Nesonycteris, and Notopteris, each represented by a single species occurring on New Ireland, the Solomon Islands, and Fiji, respectively, and a bat (*Anthops ornatus*) of the family Rhinolophidae from the Solomon Islands. Among other peculiar and interesting species are *Nycteris semota* from Hawaii, and *N. brachyotis* from the Galapagos, both related to the red bat of North America. Of rats and mice there are a dozen or more peculiar species, among which may be mentioned *Mus macleari* and *Mus nativitatis* from Christmas Island; *Epimys rattus caledonicus* from New Caledonia; *E. rattus jacobiae* from the Galapagos; *Mus huegeli* and *Mus musculus vitiensis* from Fiji; and *Mus musculus taitiensis* from Tahiti.

Among the birds the most striking forms are peshaps the Kagu (Rhinochetos) of New Caledonia, a tooth-billed pigeon (Didunculus), and a rail (Pareudiastes) on Samoa. On the Marquesas is a remarkable fruit pigeon of the genus Serresius, in the Fiji Islands a timeline bird of the genus Lamprolia represented by two species, and an orange fruit pigeon (Chrysaena) comprising three species. On the Hawaiian islands are a number of genera including Chloridops, Ciridops, Chaetoptila, Drepanis, Moho, Palmeria, Pseudonestor, Rhodacanthis, and Viridonia. Of these perhaps the ones of most general interest are the Oo *(Moho nobilis)* and Mamo *(Drepanis pacifica)* which furnished the brilliant plumage for the royal robes formerly worn in the islands. South of the Hawaiian group, Juan Fernandez, the Galapagos, Solomons, New Ireland, New Britain, and the Ker-

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madecs, are known to contain peculiar groups, including 2 families, 23 (or more) genera, and upwards of 300 species. How many unknown forms there may be, no one can say.

EXTINCT SPECIES

How many of the rare and interesting forms of terrestrial life are now extinct is unknown, owing to the rapid changes which have been going on in recent years and through increasing contact with civilization for a century or more. Zoölogical news from some of the islands is very infrequent, and an explorer may report a species from a certain island and fifty years later another reports it not found, but when the species became extinct is unknown. The equinoctial warbler of Latham was first observed in December 1777 on the occasion of Captain Cook's visit to Christmas island but no further information was received concerning it for nearly a hundred years until Dr. Streets, U. S. N., found it in 1873-74, but his specimens were unfortunately lost. There are still no specimens in collections and no additional information regarding the bird has been received since Streets' visit.

Among the birds which are now extinct the more important are: *Drepanis pacifica; Ciridops anna;* a peculiar honey-eater (Chaetoptila); and a rail *(Pennula millsi)* from the Hawaiian islands; *Aechmorhynchus cancellatus* from Christmas Island; *Prosobonia leucoptera;* and *Hypotaenidia pacifica* from Tahiti; and the monotypic *Traversia lyalli* from Stephen Island.

DESTRUCTIVE AGENCIES

The native fauna and flora of the Pacific islands are subject to destruction by several agencies, some natural and others due directly or indirectly to the work of man. Among natural agencies the more important are fire, volcanic eruptions, hurricanes, and tidal waves. Among those attributable to man may be mentioned clearing land for cultivation, introduction of firearms among the natives, introduction of domestic animals and grazing, introduction of wild mammals and birds, and plume hunting.

Fire. When the naturalist Labillardiere passed the island of St. Paul in the Indian Ocean in March, 1792, the forests of the island were on fire. The same thing may happen at any time and probably has already happened on some of the drier islands of Polynesia. Bennett in speaking of one of the islands of the Marquesas group says that wild hogs were sometimes caught by setting fire to the thickets in which they lurked.

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Volcanic Eruptions. Agassiz in his report on the coral islands of the Pacific gives maps showing the geology of the islands of Polynesia, indicating the active volcanoes. Without going into detail it is sufficient to recall the destruction caused by the volcanoes of Mauna Loa and Mauna Kea in Hawaii, and some of the results of volcanic action in the New Hebrides and in the islands of the Tonga group. Since the date of Cook's explorations Yasua on the island of Tanna in the New Hebrides has been in eruption frequently and at times almost constantly. In August, 1847, Fonualei in the Tonga group was destroyed by an eruption during which the inhabitants escaped, but the vegetation and probably some of the fauna were destroyed. On Good Hope or Niuafoou an eruption occurred in 1853 and again in 1886 when the island was covered with ashes. Megapodes and probably other birds were nearly exterminated and the vegetation of the higher parts of the island probably was much damaged. This island is only three and a half miles long by three miles wide and has an altitude of 588 feet. Falcon island, of no special interest to zoölogists or botanists since it last rose from the sea, was at one time two or three miles long and reached an altitude of 250 feet and then subsided to the condition of a breaking shoal, all in the space of a few years. The same calamity may overtake and probably has overtaken other islands on which the native fauna and flora had long been established.

Tidal Waves. Tidal waves as a result of volcanic action and earthquakes have occurred at various times and places but are frequent in Tonga. According to a recent press report, a tidal wave swept over Pangai, one of the islands in this group on April 30, 1919, devastating the island and reducing its 250 inhabitants and 50 traders nearly to starvation.

Hurricanes. On some of the islands great damage is done by hurricanes. In the Hervey or Cook Islands hurricanes occur chiefly in the months between December and March; in the Fiji islands cyclones are frequent between the months of December and April; and in the Tonga group hurricanes likewise often take place. In the Marshall Islands the Kili islets were devastated by a hurricane in 1874. Several hurricanes swept over many of the islands of the Tuamotu group in September, 1877, February 7, 1878, and January, 1903. In the storm of 1878 much damage was done to the trees and in 1903 the small brush wood was destroyed on several of the islands. It is said that in

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the storms of 1877 and 1878 the sea washed completely across the island of Niau or Greig, probably destroying ground-inhabiting species of birds if the same fate had not overtaken them during previous storms.

Clearing the Land. Agricultural development seems likely to prove the chief menace of the native fauna in the immediate future. The demand for land for planting pineapples, sugar cane, and coconuts, particularly the last, has resulted in clearing the native forests on a number of islands, particularly in the Hawaiian Islands and in some of the smaller groups farther south. Some of the Austral group, unknown zoölogically, are being similarly exploited.

Introduction of Domestic Animals and Grazing. From the days of the earliest explorers, domestic animals have been repeatedly introduced, particularly horses, cattle, sheep, hogs, dogs, cats, and rabbits. Some of the larger islands now contain several thousand cattle or sheep. The effect of grazing animals, more particularly cattle, sheep and goats, on the native vegetation is too well known to require special comment, but the work of cattle in hastening deforestation on some of the larger islands is perhaps nowhere better exemplified than on the island of Hawaii. An early as 1743 Anson found wild hogs in abundance on Huaheine Island in the Society group, and on Tinian Island in the Mariannes. Thirty years later Cook found that the natives on Tahiti and on Nomuka in the Tonga group had many tame hogs. About 1869 hogs were kept on Carolina atoll where they were fattened for the Tahiti market. Dogs which the Spaniards had set ashore on Juan Fernandez to kill the goats were reported by Anson as extremely numerous in 1741 and as they were unable to catch many goats, they had taken to eating young seals. Cook in 1773 left a pair of dogs on Tongatabu in the Society Islands, two pairs on Nomuka in Tonga, and in 1774 one pair each on Malekula and Tanna in the New Hebrides. Contract laborers returning home to the New Hebrides and elsewhere, took back cats as pets. The destructive work of rabbits is not by any means confined to Australia and New Zealand but is exemplified in striking form on some of the smaller islands of the Pacific; for instance, on Lisianski, one of the smaller islands in the Hawaiian bird reservation, formerly covered with vegetation and utilized as a breeding ground by thousands of sea birds. Rabbits were introduced about twenty years ago, and in the

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absence of enemies they increased to a point where the food supplied by native vegetation proved insufficient and disastrous results speedily followed. The rabbits devoured the native vegetation and when this was gone, died of starvation, so that three or four years ago both rabbits and vegetation had disappeared and many of the sea birds which were accustomed to nest in the grass had departed. Thus in a space of less than twenty years the introduction of rabbits entirely changed the character of Lisianski, reduced it to the condition of a bare and sandy beach or spit and this resulted in a change in the character of the bird population.

A similar tragedy was enacted on Nepean Island, at an earlier date.

Introduction of Wild Animals and Birds. Experiments in acclimatization include some interesting transfers of native species from one island to another. The Laysan finch and the rail peculiar to Laysan Island have been transferred to Midway Island where they have done well. Domesticated canaries have also been liberated on Midway Island and are now breeding in a wild state. On the island of Guam the pigmy quail *(Excalfactoria sinensis)* was introduced from Manila about 1894. The introduction of other foreign animals and birds have been less successful. Mynahs *(Acridotheres tristis)* have been introduced in Hawaii, Tahiti, and the Fiji Islands and mynahs and house finches *(Carpodacus m. frontalis)* in Hawaii, weaver birds in the Society Islands, and other species on other islands. Perhaps the most striking example is that of Oahu, where most of the birds commonly seen in the vicinity of Honolulu are introduced species. These include not only the mynahs and house finches above mentioned, but also the European skylark, California valley quail, Japanese pheasants, ring-necked pheasants, and Chinese doves. On the island of Hawaii, an Australian parrot *(Platycercus palliceps)* has become well established. Some of the experiments involving introduction of foreign animals and birds have on the contrary had disastrous effects both on agriculture and on the native fauna. Conspicuous examples are the destruction caused by the mongoose in the Hawaiian Islands and in Fiji, and by the rice birds *(Munia nisoria punctata)* to rice in Hawaii.

Plume Hunting. The pursuit of certain bright-plumaged birds of the Hawaiian islands, the feathers of which were utilized in making the royal robes, has resulted in the extermination of

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the mamo and reduced the oo to a point where it is nearing extinction. The demand for terns and albatrosses and certain sea-birds which were utilized several years ago for millinery purposes caused expeditions to be dispatched to some of the smaller islands where these birds nested in enormous colonies. Three raids of plume hunters on Laysan and Lisianski during the last twenty years have resulted in the destruction of probably a million birds. Midway Island has also suffered from the visits of plume hunters and Marcus Island was devastated in the same way about 1902. These cases merely illustrate the enormous destruction of bird life which has probably occurred on other islands of which at present no record is available.

THE EFFECT OF EXPLOITATION ON THE NATIVE FAUNA

It is neither desirable nor possible to go into detail concerning the recent exploitation of the various islands, but a few cases will illustrate the radical changes which are likely to occur in the immediate future in the progress of development. As an example may be mentioned the four islands of the Fanning group, Palmyra, Washington, Christmas, and Fanning. All are now in private hands or leased to private individuals. Palmyra is the private property of a citizen of Hawaii and for administrative purposes is now attached to the County of Oahu. Inasmuch as an exhaustive report on this island has been recently published it is unnecessary to further refer to it in this connection. Christmas Island was leased some years ago to a firm in Auckland, New Zealand. This firm planted thousands of cocoanut trees and in 1886 had a lease on several other islands and was arranging to establish groves on them. Its native fauna includes two rats and a shearwater. Washington Island is about three and a half miles long by one and a quarter in width. Of its fauna we know a peculiar species of duck *(Chaulelasmus couesi)*, a parrot *(Coriphilus kuhli)*, and a warbler of the genus Conopoderas of which the species is still unknown and no specimens are extant in any museum. Foreign labor has been imported from Tahiti for the purpose of pressing coconut oil. Fanning Island now a cable station for the cable from Vancouver to Suva, Fiji, is about nine and a half miles in length by four in width and has a large shallow lagoon. The only land birds known from this island are *Conopoderas pistor* which is peculiar to the island, and the brilliant parrot *(Coriphilus kuhli)* which is also found on

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Washington Island. The former species has never been compared with that on Christmas Island as no specimens from the latter island are now extant. Not only has Fanning Island been developed as a cable station, but labor has been introduced from other islands to collect copra, and a rifle range has been established for the employees. The effect of this development on the native fauna, comprising the two land birds and a species of duck, may be readily imagined.

In the Phoenix group immediately to the southwest, practically all of the islands were leased to the Pacific Islands Company in 1899 for coconut planting. These islands included Birnie, Canton, Enderbury, Gardner, Hull, McKean, Phoenix, and Sidney, together with the neighboring islands of Baker and Howland. Thus practically the entire group has been leased for private exploitation. Among the birds found on these islands is a species of duck *(Dafila modesta)* known only from Sidney Island and probably represented in museums only by the three original specimens. Its status is not fully understood and more facts concerning it are very desirable. The fate of such a bird at the hands of introduced laborers can readily be imagined, as it would be considered merely a wild duck and can be easily exterminated on an island which is only two miles long by one and a half miles in width.

SUGGESTIONS FOR A SURVEY OF PRESENT KNOWLEDGE

As a basis for systematic exploration and future work a general survey of all available data of the fauna of the islands should be made at once. Such a survey should include:

1. Lists of the mammals, birds, and reptiles showing the species now known from each island.
2. A check list of the birds of the Pacific region with a brief statement of the distribution of each species and a reference to the original description, type locality, and present location of the type if known.
3. A list of all introduced species including those transferred from one island to another, with full notes as to date of introduction, subsequent history, and other data regarding the experiments. This list should include also the dates of original introduction of domesticated animals.

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4. A bibliography of all publications relating to the zoölogy of the islands or bearing in any way on the distribution, habits, or life history of the various species.
5. A series of topotypes should be assembled as rapidly as possible in some central museum so that nearly related forms from neighboring islands may be readily compared. Some of the original types are no longer in existence and others are widely scattered among the great museums of the world so that such a series of topotypes would be invaluable for reference.
6. Cave deposits and kitchen-midden material should be carefully examined; skeletons, etc., should be gathered, for many species are doomed and material must be soon collected, or not at all.

Nowhere in the world can the forms from these islands be studied with the same facility as is possible in the case of those of most of the regions of the mainland. With such information and material at hand a broad foundation will be laid for future work in connection with which changes in the fauna of the islands can be recorded with accuracy and precision.

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STATUS OF WORK IN MALACOLOGY

BY C. MONTAGUE COOKE, JR., MALACOLOGIST, BISHOP MUSEUM

(Presented at the request of the Committee on Program.)

According to your request for a statement relative to the condition of work to date on terrestrial malacological problems in the Pacific, I would say that most of the work is still undone.

Valuable monographs dealing with different genera have been prepared and I might mention those by Pilsbry in "The Manual of Conchology," Crampton, Mayor, and Hartman. Since Garrett's time, in the eighties, as far as I know, very few lists have been published dealing with the total shell fauna of groups of islands except one by Tom Iredale, covering the Kermadec Islands. Up to the present time, far too little attention has been paid to genera of the small and minute specimens, nearly all collectors spending their time on the large and showy species, as, for example, the many monographs dealing with the genus Partula. The only minute families living in the Polynesian region that have been monographed to date, as far as I know, are Pilsbry's publications dealing with Tornatellinidae and Pupillidae in volumes 23 and 25 of "The Manual of Conchology."

My suggestion is that intensive collecting be done on each group of islands of the Pacific and that papers dealing with the entire shell fauna as known from a group of islands or a single island should be published. A large amount of time will be necessary to accomplish this, when we consider that probably not one-half of the species of the Oahu fauna have been described. Later, papers dealing with the different groups of islands could be generalized into a survey of the whole Pacific.

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PROGRAM FOR WORK ON LAND MOLLUSKS

By Henry A. Pilsbry

As land mollusks are an important group in zoögeography, it is recommended that material for a comparative study of the soft anatomy of land snails should be obtained from all the high islands of Polynesia, Micronesia, and Melanesia. At the same time, faunistic collections should be increased as much as possible by examining islands not now known or only superficially collected over. At present the inequalities in our collections stand in the way of definite comparisons of island faunas. The reliability of our estimates of the relationships and probable source of a fauna increases directly with the completeness of our collections and the right appreciation of the systematic relations of the genera and species. In a number of Polynesian families, such as the Zonitidae, the taxonomy is now nebulous. Being based on the shells alone, it is empirical, since the important features are in the soft anatomy. In others, such as Partulidae, the relations of the groups on different islands are uncertain, and afford no solid basis for tracing the streams of migration. The collection and preservation of specimens with the soft parts is urgently needed.

It is believed that except in Hawaii, collectors have given their main attention to the larger shells. Where Partula, Placostylus and the like are to be found, the small and minute snails generally have received scant attention. By modern methods of collecting it is believed that large and important additions can be made on any high island. Such collecting has vastly increased our knowledge of the Hawaiian mollusk fauna in the last few years.

A beginning may well be made on especially important points. I would suggest the Marquesas, Rapa, any high islands of the Austral group, Samoa and Fiji. Further north, some of the Caroline group appear to be degraded high islands with interesting faunal peculiarities. The Pelew group also deserves attention.

Since over-sea drift is thought to be a factor in the dispersal of non-marine mollusks, the limit of toleration of sea water should be ascertained for small land snails of different genera. To be of any value the experiment should approximate the natural conditions in the open sea. For instance, snails should be allowed to seal themselves to branches, in knot holes, or to

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crawl under bark. The objects should then be moored to a stake by a line permitting free drifting. Among marine mollusks the duration of free-swimming stages should be ascertained for as many genera as possible. The distribution of forms without a floating larval stage should be determined in detail. Such work could be carried on at Honolulu or Pearl Harbor and would afford some definite data where now all is guesswork.

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DIRECTIONS FOR COLLECTING LAND AND FRESH-WATER MOLLUSKS

By Henry A. Pilsbry

APPARATUS

The only apparatus absolutely essential are sharp eyes and a bottle or box to contain the specimens, but part or all of the following are needed for the most efficient collecting:

Forceps with very weak spring, fine points, 3/4" long.

Eye, dental, or hypodermic syringe, the point blunted to give proper stream.

Hooks (readily made by heating and bending the point of a small hat pin).

Wide-mouthed, four-ounce bottles with corks.

Vials and small boxes for little shells, and chocolate-tin or other containers for larger specimens.

Cheesecloth—plenty of it—and cotton for packing.

A strong "landing net" frame, to be fitted with cheesecloth or unbleached muslin bag for "sweeping," or with burlap or other loose material for scraping the bottom in ponds or streams. A quarter-inch wire, bent into a circle, with two ends at an angle for lashing to a stick or pole serves equally well.

Alcohol.

Stout paper for labels.

When a snail is found in abundance, take plenty; it may not be found anywhere else. Many snails are very local—in a single valley or smaller area. A "dead" shell is far better than none, but get living ones if possible.

PREPARATION OF DRY SPECIMENS

After drowning, the animals of large snails may be "squirted" with the syringe or pulled with a hook or pin; those from one locality wrapped in cheesecloth, labeled, and hung up to dry in the shade. Pack only when thoroughly dry, as otherwise they are likely to mould.

Small and minute shells (except those preserved for dissection) may be placed in alcohol at once to kill them, then dried, or left in the alcohol. The latter is safer in hot, humid climates as there is danger of moulding. This applies to Pupillidae, Tornatellinidae, and others of that size. Never use formaline. In the absence of alcohol, use whiskey or other strong spirit.

Drown snails by immersion in a vessel full of water, 12 to 24 hours—until the extended animal is not sensitive to the touch. Transfer to about 33 per cent alcohol; after 24 hours to about

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66 per cent. After curing thus, mollusks may be packed for shipment with only enough alcohol—66 per cent—to keep them moist. Alcohol used for curing may be used again by adding a little fresh alcohol; the exact proportions are not essential. Snails placed at once in alcohol contract so much that dissection is difficult or impossible. If single specimens or very few are found, the animal may be removed and pickled and the shell preserved dry, care being taken to give both the same number. This applies chiefly to large or medium-sized snails.

Small shells, up to half an inch long, may be collected in vials. Fill the vials with water over night, then replace most of the water with alcohol. Such vials may then be plugged with cotton and packed standing in fruit jars, with cotton between layers and a little alcohol added. Add a label in the vial.

Fresh water snails often cannot be killed extended, but slow narcotization by adding tobacco or tobacco and alcohol to the water is sometimes effective. Quite small operculate snails may be killed extended by suddenly pouring boiling water over them when active. If opportunity allows, observe the locomotion of land operculate snails, whether evenly gliding, advancing the right and left sides alternately, "stepping," etc. Is the muzzle (or oval disc) used in locomotion?

WHERE TO LOOK FOR SNAILS

Snails may be looked for on the bark and leaves of trees and shrubs; in knot holes and under bark; on bananas, ferns, and herbaceous plants, chiefly in the humid zone.

Many minute snails, like Pupillidae and Tornatellinidae, are found on trees—mossy trunks in the humid zone, but also in rather dry places, in crevices of bank or under loose bark. They are often very local, plentiful on one tree; rare or wanting on others. Don't give up the search too soon. Many species are as small as a tenth to a twenty-fifth of an inch in diameter.

Look on and under rotting wood on the ground; also in the leaf debris of woods and thickets. Collect a peck or so of this debris in bags (salt or flour bags serve very well), or in squares of cheesecloth, to be looked over at home, or dried, concentrated by rejection of coarsest materials, and shipped to be sieved and looked over with a lens in the laboratory. *This has proved to be one of the most productive methods.* By this method shells are found which would never be seen in the field.

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Fallen palm and banana leaves should be looked over for small snails; they are often productive. Look also under stones, on ledges of cliffs and around ruins and abandoned buildings.

The "landing net" with bag of cheesecloth or unbleached muslin may be used to beat and sweep grass and ferns for minute leaf-inhabiting snails. A cyanide bottle should be at hand for killing the insects obtained incidentally.

Fossil shells are often to be found in quantity in superficial soil where there was formerly forest. They should be looked for also on and around raised reefs, sand dunes, aeolian rock, in ravines or gullies at low elevations, and on arid volcanic cones. Such deposits are very numerous in Hawaii, probably also in Polynesia. They usually contain species now extinct, sometimes extinct genera, and are of the first importance. Deforested places or islets are highly promising situations for exposures of such deposits. When shells are abundant, scoop up shells and sand or earth in quantity to be picked at home.

Fresh-water shells inhabit most streams. When possible, collect at several places in the same stream, noting distances and elevations. At different levels ecologic forms of the same species usually occur; also in the intertidal flats where streams debouch. Examine dripping rock faces.

Rice or taro plantations have other species. Look on lily pads and their stems. Masses of fine water plants should be hauled out, partially dried, and shaken over a paper or cloth.

The landing net frame fitted with a burlap bag is indispensable for collecting fresh-water shells living buried in mud or sand.

LABELS

Write with soft pencil on a tough paper. Note island, locality, station where found (as under stones, on ferns), and if few shells are collected, note approximate elevation, humid or arid conditions. If the locality is productive, the particulars may be entered in note book. The fuller the record is, the better; but if time presses, note at least the locality and elevation.

Collectors of mollusks should always carry a cyanide bottle for insects. The collection of insects and plants can be carried on very well with mollusks; but it is a mistake to collect in too many branches.

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Collectors should be provided with a little handbook of a few pages with photographs, giving what is known of the island or archipelago under examination, and directing attention to particular desiderata. These can be supplied by Cooke, Pilsbry, or others on application to the Bishop Museum.

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STATUS OF THE GENERAL KNOWLEDGE OF THE PACIFIC FORAMINIFERA

By Joseph A. Cushman

FAUNAS

In order to understand the foraminifera of any region it is necessary to study them as belonging to several distinct faunas as follows:

Pelagic. There are comparatively few species, about thirty, which are truly pelagic. Of these perhaps only ten are very common. These are largely species of the genera Globigerina, Orbulina, Candeiana, Hasterigerina, and Pulvinulina. These pelagic species are very widely distributed over the whole of the ocean. This is similar to what is known of other pelagic animals and plants. As far as the knowledge of the Pacific at present shows, the distribution of the pelagic foraminifera is very largely determined by the force and direction of the ocean currents. Most of the species belong to the family Globigerinidae.

Abyssal. In the case of the abyssal faunas, temperature seems to be the controlling factor in their distribution. The ocean bottom as a whole at considerable depth is cold, usually 40° F. or less. As a result in equatorial regions there are found species and genera under such conditions which are typical of the more shallow but cold water of polar and subpolar regions. In the deep-sea forms arenaceous types predominate, especially those belonging to the families Astrorhizidae and Lituolidae.

Reef Faunas. In this division are included those species which are found in very shallow waters, often in the lagoons inside coral reefs, mostly water of less than 20 fathoms, but extending out in some cases to 40 fathoms. These include many of the largest living foraminifera, such as Orbitolites, Amphistegina, Heterostegina, Operculina, etc. It is also the one great region in which the Miliolidae are obtained in greatest abundance. With these are many Nummulitidae, Rotaliidae, and some Textulariidae.

Medium-Depth Faunas. At depths from 100-300 fathoms, corresponding to the edge of the continental shelf, there is obtained a very rich fauna in which Lagenidae and Textularidae predominate.

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The last two of these faunas, those of shallow water, and those of medium depths are much the most interesting as they are more apt to contain new species and those of restricted distribution.

RELATION OF THESE FAUNAS TO THOSE OF OTHER REGIONS

As has already been noted, the pelagic forms of all the great oceans are very similar in their species. The same may be said of the abyssal forms to a lesser degree. In the case of certain of the abyssal arenaceous forms there seems to be a very limited distribution as far as present knowledge shows. The genera are often very widely distributed and the species themselves are often very restricted. Oftentimes such species occur in enormous numbers as has been noted in the collections south of the Philippines where certain species make up almost the entire mass of the bottom. It is in the shallower water faunas, however, that the greatest diversity of species occurs. As a rule the coral reef faunas have in some cases a very local range, in others a range taking in the general Indo-Pacific region. There is often a great predominance of a few species, and a great many other species represented by a very few specimens. Certain of the species, however, are localized, as for example, *Baculogypsina sphaerulatus* and *Siderolites tetraedra,* the former occurring in the Australian region and very abundant in the shallow waters, the latter wanting in the Australian region and very abundant in the Philippines. In the faunas of medium depths while certain species are more abundant than others there does not seem to be a great predominance of any particular species at the expense of others. With these last faunas there is more or less localization of certain species if faunas from different regions are closely compared.

HISTORIC SKETCH OF WORK ON THE PACIFIC FORAMINIFERA

The Pacific has had much less work done on the foraminifera than most of the other great regions of the ocean basins. Certain areas, however, have been more carefully worked than others. While there are scattered records from the Philippines and other regions previous to the *Challenger* Expedition, they are mostly unrelated notes from small sporadic collections. The *Challenger* work in the Pacific covered the following route: from Melbourne and Sydney to New Zealand, north to the Fijis and thence through the East Indies to Hongkong, and back through the Philippines to the north coast of New Guinea

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and the Admiralty Islands, and thence north to Japan. Afterward the route swung eastward to the longitude of the Hawaiian Islands, thence south through that group and the Society Islands to about 40 degrees south; thence eastward to the coast of South America. In his work on the foraminifera of the *Challenger* Expedition, Brady describes many new species from this general region, especially from medium depths. Some of the faunas are very rich, such as that from Torres Strait, from the Philippines, and from some of the oceanic islands. A reference to his figures and descriptions shows that many of the species from this region referred to previously described forms should not be so referred and that the proportion of new and rare species is probably much greater than Brady recognized. Later work has shown that many of these species are rather localized in their distribution. Chapman has published numerous papers on the general Australian region and has worked up very much in detail the faunas in the region about the Funafuti Atoll. These cover both the shallow-water species of the region and the dredgings out into deep water, giving a very concise knowledge of a limited area of this general faunal region. Goës in 1896 published a paper on the foraminifera obtained by the *Albatross* from off the Galapagos Islands and the west coast of California, Mexico, and Central America. Very few of these records, however, are in anything but the deeper water dredgings and give very little information in regard to moderate or shallow depth. Millett published a detailed paper on the foraminiferal fauna of the general region of the Malay Archipelago, taking in mostly shallow water but some deeper stations. While he published a number of new species and varieties his figured specimens show that many of the species referred to older names are really very different and a study of the Philippine dredgings has confirmed this. Flint's work on the *Albatross* soundings published in 1899 is mostly on the Atlantic dredgings, but there are a few records from the east coast of the Pacific. These are, however, very scattering and add only slightly to Brady's knowledge of the area. Rhumbler worked up some rather meager collections from Laysan and Chatham Islands, mostly from shore sands. His paper shows that there is here a problem of localized species and this is probably typical of what would be found if such material from widely separated points in the Pacific were carefully studied. The large collections of the *Albatross* Hawaiian Expedition

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were largely destroyed, but a few remaining bottom samples, almost all from comparatively deep water, were worked up and published by Bagg in 1908. While the list of species is considerable it does not at all represent the most interesting faunas of this region which the *Challenger* dredgings from off the Honolulu reefs show to be rich and varied. Between 1910 and 1916 I published a series of papers on the north Pacific from the *Albatross, Nero,* and *Tuscarora* soundings. Most of these are from comparatively deep water but are from well scattered stations over the general region and give a very fair knowledge of what the deeper water faunas are in different parts of the Pacific. From off Japan a series of shallower water dredgings are available and give a better knowledge of this general region than most other parts of the Pacific as many of the species were plotted on maps and a study of their distribution showed that there were developed definite faunal regions. Sidebottom has written two detailed papers on the various species and varieties of Lagena found in the southwestern Pacific, showing what may be expected when other genera are worked up with equal detail. More recent papers by Chapman, Sidebottom, Mestayer, and myself have given a very good idea of the fauna of the New Zealand region as developed in water of medium depth. This has shown that there are here developed numerous localized species and varieties. This list of authors and papers would seem to show that a considerable amount of work has been done upon this area but when this is compared with the wide extent of the Pacific, the region as a whole has hardly been touched, especially some of the more interesting parts of it as will be noted later. There is in press a large report on the *Albatross* Philippine Expedition, the material of which was placed in my hands a number of years ago. This includes not only the Philippine Archipelago but also the region southward to the Equator and beyond, and includes a large number of carefully made dredgings, mainly in shallow water and that of medium depth, and also a few from fairly deep water. A study of these has revealed a large number of new and evidently localized species and probably makes this region the best known of any area of equal size in the Pacific.

REGIONS OF THE PACIFIC BEST KNOWN

As just noted, the Philippine area is the best known and as the area laps over that from which Millett's Malay material was

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obtained, this whole part of the Pacific is better known than most other parts of the world. The region of the Funafuti Atoll has been very carefully worked up in detail by Chapman, and the New Zealand area and some stations off the coast of Australia are fairly well known in detail.

REGIONS OF THE PACIFIC WHERE MOST WORK NEEDS TO BE DONE

From the foregoing it would be apparent that the general region of the Pacific, except those portions noted, needs much work before any fairly complete knowledge of its faunas can be obtained. Certain areas, however, need work more than others. A large part of the Pacific ocean basin is characterized by red clay which is not prolific in the number of foraminifera present. By far the most interesting areas will be those of shallow and medium depths. Very little is known of the local faunas of the great majority of the islands of the south Pacific and it is probable that in those many new species will be found, together with many interesting problems of distribution. Except for the few stations dredged by the *Challenger* off the coast of Chili, and the specimens described many years ago by d'Orbigny, almost nothing is known of the foraminiferal fauna of the shallow water and medium depths of the entire coast of western America, and this should prove to be very interesting, both in its problems of distribution and the new forms which will certainly be obtained. The region of the Hawaiian Islands including the Midway group should also give interesting data in regard to distribution northeast of many of the species of the Australian and East Indian regions.

PROBLEMS OF GEOGRAPHICAL DISTRIBUTION AND INTERPRETATION OF GEOLOGIC SEDIMENTS

In general it may be said that in the Indo-Pacific and Australian regions there are now living more ancient forms than are found in most other parts of the ocean. Certain genera such as Nevillina, which has been found only in the localized area in the Sulu Sea, represent such forms. The nearest relatives to Nevillina are found in the Cretaceous of southwestern Europe. A similar case is that of *Siderolites tetraedra* which in closely related forms may be traced from the Chalk of Meistricht, Holland, through the Eocene of Italy, to the recent waters of the Philippine region. There has also been a migration into the region from the east as shown by the close relation of the lower Oligocene of the coastal plain of the United States, such as that

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of the Byram Marl to the fauna now living in the region off Australia. Certain of the more ancient types of Frondicularia are now only to be found in the Indo-Pacific and Australian regions. In the shallower waters about many of the islands in the tropical Pacific are now living great numbers of the larger forms of Orbitolites, Operculina, and Heterostegina, which were characteristic of the Eocene of a very widely distributed area. These larger forms now so abundant only in this region were at one time characteristic of the dredgings throughout the world and are one of the larger constituents of the thick limestones built during the early Tertiary which extend across southern Europe, northern Africa, and southern Asia, and found also in tropical America. A study of the conditions under which these forms now live in the Indo-Pacific would do much to solve the ecologic conditions under which these great masses of limestone were originally formed.

A study of the borings from the various coral islands of the Pacific should do much to determine some of the questions now in dispute in regard to the formation of the coral reefs. A study of the foraminifera from such borings should be easily made and they could be compared with the present day faunas of similar localities.

In general a study of the foraminiferal faunas of shallow waters, and those of medium depths made in the various parts of the Pacific already indicated, can do much to solve many problems and would probably do more to advance the knowledge of this group than would the study of any other regions from which the collections can be obtained.

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NOTES ON THE COMPARATIVE STUDY OF LITTORAL FAUNAS OF THE PACIFIC ISLANDS

By Hubert Lyman Clark, Museum of Comparative Zoölogy, Cambridge, Mass.

(Presented at the request of the Committee on Program.)

THE PROBLEM STATED

So far as I know very little work has been done on the comparative study of the faunas of different islands, in any group of marine invertebrates. The bibliography of the subject is very brief, if it exists at all. It has been a very generally held view that the littoral faunas of all the islands between Mauritius and Hawaii, inclusive, are essentially the same and that their comparative study would be of little value.

My visit to Torres Strait in 1913 and the study during the past seven years of the Echinoderms of that region has opened my eyes to the fact that the littoral faunas, or at any rate the littoral echinoderms, of different islands even only a relatively short distance apart may be quite unlike. One would have supposed that the echinoderms of Torres Strait would be identical throughout the Strait; that is, the echinoderms of an island at the eastern end of the district would be identical with those found at the western end. Such, however, is not the case. Moreover, now that we know it is not the case, a plausible explanation of the facts is possible and the whole investigation throws light on the geological history of Torres Strait as well as the history of the marine fauna of Australia.

If islands in the Torres Strait region only a little more than a hundred miles apart show such important differences in their littoral faunas, it is reasonable to believe that similar critical study of the faunas of eastern New Guinea, Fiji, Tahiti, the Paumotus, Easter Island, the Marquesas, Hawaii, the Marshalls, the Carolines and Pelews (not to mention a dozen more equally interesting) would throw light on the history of the Pacific islands which can be secured in no other way. Of course you will understand that I do not mean it is the *only* source of light on the subject. I mean rather that it offers a unique gleam of light from one particular point. I have no doubt that such a study would be amply justified by the results.

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METHODS OF STUDY

As to the best method, I have no doubt that the most complete and the most reliable results would come from the intensive study of selected areas by selected men. Were sufficient money available, my plan would be as follows:

Select certain definite areas, preferably single islands, well distributed over the Pacific, for the stations. These should be about a dozen in number at least, more than that if possible. Their relation to ocean currents, to commercial routes, and to lines of human migration (so far as these are known) should be carefully considered. Their geological structure, climate, and present inhabitants must also be taken into account.

If only the problem I am concerned with were to be considered, two men could undertake the work but it would be much better to have the party consist of at least four or five men, perhaps six would be still better: One anthropologist, one geologist, one botanist, a "land" zoölogist and two marine zoölogists. Of course two marine zoölogists could not "cover the ground." They would have to work in certain selected groups, ignoring the rest. Any one of these six men could do his work without the others and perhaps it would not be feasible to correlate the field work of an anthropologist and a marine zoölogist. The latter might wish to spend weeks at an uninhabited island! Frankly, the number of men is a matter that varies directly with the amount of money available.

Each station ought to be visited at least twice at different seasons of the year. If one visit were in the spring, a second should be made six months later. The length of sojourn at a station would vary from two weeks to two months, according to local conditions. Probably not more than six stations a year could be occupied and since each must be occupied twice it would take four years to cover the dozen stations. It is moreover obvious that the best results would come from periods of museum work alternating with field work, and of course periods of complete vacation and change of scene would be necessary to keep the workers in shape. Evidently therefore a period of about ten years must be regarded as a minimum for the completion of such a survey as I am outlining.

During the stay at a station as intensive a study of the group in hand should be made as local conditions (of which weather would be most important) permit. At the same time, extensive

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field notes should be made and good series of every species preserved. At least once each year, return should be made to Honolulu, with the accumulated collections which could then be gone over and identified. At least once in three years a report should be prepared and published on the work accomplished. I sincerely believe the best results would come from one man doing both the field work and the report-preparing in each group, and it is of particular importance that the same man should visit *all* the stations. But of course time could be saved by having the reports prepared by men at home, leaving the field work to be done by others, for field work and report preparing could then go on side by side (in time, I mean; obviously not in space). Much could be done if anthropologists, geologists, botanists, et al, made general collections of everything in the way of animals to be found on the reefs, but such general collections are apt to contain only the more common things. The general collector unavoidably overlooks many animals that a specialist sees at once. I therefore favor very strongly sending specialists and having each specialist stick to his job so far as possible.

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MEDICAL ENTOMOLOGY ABOUT THE PACIFIC

By David L. Crawford

The medical phase of entomology is comparatively new and of very greatly increasing importance all over the world. It is now recognized by the medical profession and health experts that the most direct method of combating certain diseases is to suppress or control certain insect species which act as transmitters of the disease-causing organisms ("germs").

The famous work of Walter Reed on yellow fever, of Ronald Ross on malaria, and of others on these and other diseases and their insect-transmission is so familiar to all that it needs no exposition here. The investigations of these men are having practical results in the extensive checking of malaria, yellow fever, bubonic plague, typhus and several other diseases which are insect-borne.

The lands about the Pacific Ocean are, of course, sharing in this great benefit to humanity and can do so even to a much greater extent by applying principles and methods already known by science. There are, however, several insect-borne diseases characteristic of the Pacific which must be studied carefully before their control can be effected. To these I would call special attention because of the challenge offered for research work of the utmost economic importance.

Elephantiasis is a horrible and extensively distributed disease caused by a nematode worm of the genus Filaria. It is known that mosquitoes are involved in the spreading of the disease, but there is a paucity of knowledge on the entomological phase of this problem which is greatly retarding its successful solution. A specialist stationed in Samoa, for example, could doubtless work out this problem in a few years and confer a tremendous benefit upon mankind.

Kala-azar is another destructive disease of the paleotropics which is believed to be insect-borne. Our knowledge of this, however, is very meager and must be extended without delay. Other fevers and deadly diseases caused by protozoa distributed by insects occur commonly in South America and humanity must be delivered from them by the work of entomologists.

A trypanosome disease allied to African sleeping sickness occurs in Brazil and threatens to be spread northward if we do not check it.

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Dengue fever, though not commonly deadly, is a very troublesome disease which occurs throughout the tropical areas of the Pacific. And yet we are not even sure that it is, or is not, insect-borne! We must know this, and if it is insect-borne, we must know how the transmission is effected.

Still other diseases are demanding our attention: Oroyo fever, spotted fevers, espundia and others. Organized campaigns of study of each of these diseases in its most favorable localities are necessary before mankind can be freed from them.

The tropics cannot be utilized to their full, nor can they contribute their share of the world's goods, until certain of these diseases are under control. Thorough entomological study is essential before control of the diseases is possible. Moreover without this thorough study and subsequent control work, many countries and areas now free from these diseases are sure to be invaded sooner or later by dissemination of the insect agents or the disease germs.

Every consideration is an urge to immediate and thorough and fully sustained study, entomologically, of these Pacific diseases which are, or may be, transmitted by the agency of insects.

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NEED OF FURTHER STUDY OF THE INSECT FAUNA OF HAWAII AND OTHER PACIFIC ISLANDS

By O. H. Swezey

In the "Fauna Hawaiiensis" we have a comprehensive presentation of what had been done up to that time with the land fauna of the Hawaiian Islands. A great part of this publication is taken up with the insects, which in number of species far exceeds any of the other classes of animals in the Hawaiian land fauna. Of the insects there are 3245 species listed in "Fauna Hawaiiensis," many of them described for the first time. of which 2740, or 84 per cent are considered as endemic species.

As is well known, this great monograph is based on the collection and study of the fauna by R. C. L. Perkins during a period of about 10 years (1893-1902). It furnishes the foundation for all future work on the native insects of Hawaii. At one time it was considered by some that there was no more to do, that the exploration and the discovery of new species was completed, and that no more new species could be found. In the "Introduction" to "Fauna Hawaiiensis" (which is composed largely of biological considerations of the insect fauna), Dr. Perkins states that he considers about half of the existing species of native insects to have been collected. The fact that about 300 species have been described since the "Fauna" was issued, chiefly from incidental collecting by local economic entomologists, shows what great possibilities there are and it is an indication that many more species would readily be found if one or more entomologists were devoting their whole time to the collecting and study of the native insects. In fact, whenever any one of the local entomologists spends a day collecting in what is to him a new location in the native forest, he hardly ever fails to secure something new. Considerable recently collected material has accumulated at the Bishop Museum which is yet unworked. and in the hands of members of the Entomological Society is new material waiting to be described, while some lots have been sent away to be worked up. Much information of a biological nature has been published in the Proceedings of the Hawaiian Entomological Society. Thus progress is continually being made towards a more complete knowledge of the native insect fauna.

At the Bishop Museum, an attempt is being made to build up as complete a collection as possible of the Hawaiian insects.

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That there is great need of much collecting for this is evidenced by the "Summary of Insects in the Museum Collection" published in the Director's Report for 1909, which showed that at that time the collection contained only 64 per cent of the species included in "Fauna Hawaiiensis." Since that time more material of the Perkins' collection has been received and some later numbers of the "Fauna" have been issued. A revision of the above summary with respect to these later additions shows that the Museum collection has specimens of only 55 per cent of the insects described in "Fauna Hawaiiensis," and as the Museum collection is at present the most complete of any in Hawaii, it is evident that a great deal more collecting must be done in order that there may be in existence in Honolulu specimens of as many of the already known Hawaiian insects as possible.

The collection of new species is also very important. We have sufficient evidence that there are many more species yet to procure before we can have complete knowledge of our insect fauna. The fact that by incidental collecting, new species, and an occasional new genus also, are continually being brought to light, is sufficient indication that there are many more yet to be obtained. This is evident also from the fact that in "Fauna Hawaiiensis" there are a great number of species described from single specimens. Take for example the Microlepidoptera with 440 species. Dr. Perkins secured only a single specimen of 25 per cent of these species. This is of itself an indication that there are many more species to be found, for the catching of a single specimen of a species may be considered as an accidental catch, which, if missed, would have left it among the many others which likewise missed being caught.

In the "Fauna" each specialist who worked up a group of insects, dwelt somewhat on the consideration of the inter-island distribution of the species, and showed from the collection at his disposal that a large proportion of the species occurred only on a single island. Since, as shown above, so many of the species are based on single specimens which are to be considered as accidental captures, and since more recent collecting has shown that some of the species previously considered single-island species are widely distributed, it is certain that more thorough collecting would modify conclusions previously arrived at concerning the inter-island distribution. The evidence that this may give toward solving such problems as

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whether the islands were ever connected, and, if so, how long they have been separated, or whether they have always been isolated, makes an exhaustive entomological survey of large importance.

Dr. Perkins considered that about 300 species of native insects might have been exterminated before they were known to entomologists, by agricultural and grazing operations, and particularly by a species of foreign ant (*Pheidole megacephala*) which has continued its spread up the ridges into the native forests, much to the deteriment of the endemic insect fauna. There are large regions in which the native forests have been destroyed by cattle, and such depredations are continuing. The forests in places are dying off for other reasons, in some places no doubt from old age. The disappearance of the forests for whatever reason, results in the destruction of many of the native insects of those regions; and it is certain that many species are now being exterminated in this way, some of which may never have been collected, and others though they may have been recorded, are not at present represented in any collection.

The importance is thus emphasized of more extensive collecting before it is too late, particularly in the regions where the native forests are disappearing, and also in regions not previously visited by entomological collectors, some of which are now more accessible than formerly, by trails following irrigation ditches, or penetrating the forests for other reasons.

Besides the mere collecting of specimens, there is great need of observations and further study of the habits, life histories, seasonal occurrence, parasite relations, plant faunas and other problems. The habits and hosts of many of the well-known insects have not yet been ascertained, and it is self-evident that nothing is known of those many species of which but a single specimen has yet been seen.

The insect fauna of the Hawaiian Islands has been more thoroughly explored and studied than has that of any other Pacific island group, yet much is lacking. The fullest knowledge possible of the Hawaiian insect fauna is essential to one making an entomological exploration of any of the other Pacific island groups for the purpose of studying relationships of faunas of the different groups of islands, or of the Pacific as a whole. Not only should he know what kinds of

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insects to look for but how to find them; for it is of great importance to ascertain whether any, or many of our most obscure insects have allies in these other island groups. Anyone not knowing them and how to find them in Hawaii, would be most likely to overlook much of importance in collecting in the other islands. The collector should be familiar especially with the Hawaiian flora and with the insects attached to the different plants and trees so as to know what to look for on the trees of the same or related genera. For example, the trees of the Hawaiian islands which are most remarkable for their large insect faunas, or which have very peculiar or interesting species attached to them, should be particularly worked over in any future explorations. We want very much to know what kinds of insects are found on Metrosideros in other Pacific islands, whether similar or related to the interesting fauna which this genus of trees has in Hawaii. The same could be said of the koa, and the genus Euphorbia, the various members of the Lobelioidea, the Rubiaceae, the banana, and many others: in fact, nearly all of the common genera in Hawaii should be the object of special search for insects occurring on them, if these genera are found in the islands being explored.

Knowledge gained in collecting work in the Hawaiian islands is of eminent importance in fitting one for such collecting in other islands. The collector should also become familiar enough with the foreign insects in Hawaii to distinguish them readily from the endemic species. There are many species of insects which will no doubt be found common to all the islands of the Pacific, especially those carried by modern commerce, as well as those to be considered as natural immigrants that have become widely dispersed throughout the Pacific in quite recent times. The ability to distinguish these from what would more properly be endemic, would be gained by extensive collecting in the Hawaiian group, and such knowledge would save much valuable time and efforts on the part of the explorer in foreign fields.

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AN AREA SUITABLE FOR OCEANOGRAPHIC RESEARCH

BY C. M. FRASER

The portion of the Pacific bordering the coast of North America from Cape Flattery northward to the Bering sea and including Puget sound and the Vancouver island region provides a situation where it should be possible to get far-reaching results from the very beginning of operations, with the minimum of effort.

The much indented coast-line with its deep fjords, the myriads of islands, large and small, make an endless variety of channels through which the waters of the great rivers are permitted to mix with the saline waters of the open Pacific, over a continental shelf, which, in places, reaches a width of more than one hundred miles. The great variation of current and tide, of temperature and salinity, induced by such conditions in the inshore waters, finds a suitable parallel farther out to sea, since at one time the Japan current or its offspring, the Alaska current, may seem to predominate in its influence and at times the northern drift, usually nearer shore, is more significant.

From the standpoint of physical oceanography, the problem is a complicated one, but the work already done serves as a good basis for future work. The Canadian Hydrographic Survey and the United States Coast and Geodetic Survey have charted much of the inshore waters, particularly in the vicinity of the harbors and along established traffic routes. The tide and current survey of the Canadian Department of Naval Service has been obtaining information for several years as to the time, direction and force of tides and currents but their efforts have been largely confined to the same regions as those taken by the hydrographers.

An extension of this work to less frequented areas and out farther from shore to embrace the more distinctly oceanic currents, is urgently needed. Even with vessels and apparatus of the nature of those used at present there is no special difficulty in the way of making this extension, but since the present equipment is being used full time, the extension can be made only by an increase in equipment and personnel.

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The work is, and presumably must be, done largely under the authority of the governments of the respective countries, hence only to them can an appeal for greater facilities be directed.

From a biological and biochemical standpoint the region offers equally favorable opportunities, particularly when taken in correlation with an expansion in physical oceanography. The province of British Columbia alone, although it reaches through little more than eleven degrees of latitude, is credited with seven thousand miles of general coast-line and twenty-five thousand miles of tide line. In a portion of the coast of Alaska the coast-line is multiplied in a somewhat similar way. With this naturally goes an endless variety of shore, with an endless variety of conditions along the shore, due to differences in strength of current, degree of salinity and change of tide (which in some areas reaches twenty-five feet or more). This with the great width of the continental shelf provides for an extraordinary richness both in biological species and in the number of each species.

On account of the various physical and chemical differences, it is a difficult matter to explain the distribution of many of the species, as species commonly found as far south as the tropics or nearly related to these may appear almost side by side with others from the Polar seas. The ecology of the region can therefore be understood only when a more complete oceanographic survey, physical and biological, supplies the necessary data.

From an economic standpoint this is of great importance since so many of the species are of economic value. One naturally thinks of such fishes as the salmon, the herring and the halibut, but they are by no means the only forms of importance. To know something of the life-history of these species of economic value as well as others directly or indirectly related to these, a biological and biochemical survey is necessary.

Here again, although the problem is complex, immediate results of value would accompany the extension of the work. A good start has been made in the three biological stations in this region, at which work has been done; the Pacific Coast station of the Biological Board of Canada, at Nanaimo, B. C.; the Puget Sound Marine Biological station at Friday Harbor,

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Wash., and the Minnesota Seaside station at Port Renfrew on the southwest coast of Vancouver island. The work at these stations has as yet been confined to rather restricted areas surrounding each station. Besides this, at wide intervals, expeditions have been sent to other parts of the coast and these have collected material and data.

Since in the resolution in the section of marine zoology, passed by the Conference, it is stated "that the investigation be carried on, insofar as possible, through existing agencies, such agencies to be provided with the additional apparatus and facilities necessary, such investigation to be carried on under such cooperation as will prevent duplication of effort," here is surely a case in point. The biological stations already in the region have made a start on the work. There can be no great difficulty in extending it, particularly as such cities as Seattle, Bellingham, Victoria, Nanaimo, Vancouver, Prince Rupert and Ketchikan, together with many smaller centers are all interested in the fisheries and through the fishermen could give valuable assistance as well as serving as bases of supplies, so that no matter where the work was being done, it would be within easy reach of at least one of these.

Although this work has received Government assistance, there is nothing to prevent the making use of assistance from any or every other source from which it may come. The main need is that for a boat, suitably manned and equipped for work on the continental shelf. Such a boat should be large enough to stand the buffeting of the open ocean but not too large to be expensive to run. One type of the larger halibut boats, 80 or 90 feet in length, and fitted up for gettting hydrographic, physical, biochemical, bacteriological and biological material and data, would be very satisfactory. With such a boat, $50,000 a year for carrying on the work and a suitable personnel, results of value could be obtained from the beginning.

An area on the Swiftsure shoal, to the southwest of Vancouver island at the entrance to the strait of Fuca and a larger area extending northward from Vancouver island, through Hecate strait, past the Queen Charlotte islands, would serve as excellent points of attack. Later such work should be supplemented by and correlated with work done by a larger vessel in deeper water further off shore.

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BREEDING EXPERIMENTS

By Paul Bartsch

The reason why I wish to bring before you the results of some of the breeding experiments which it has been my good fortune to make under the auspices of the Carnegie Institution is because I felt that here in Hawaii and in the islands to the south and even in the Philippines we have groups of organisms that would lend themselves to parallel efforts; and I believe that by making these parallel experiments it will be possible to determine whether the results are merely individual expression or whether they express a biological law.

In the Hawaiian Islands we have the Achatinellas, that wonderful group of beautiful land shells, and the Amastras. A little farther south and west we have the Partulas, another greately diversified group of snails, while in the Philippines the Cochlostylas should lend themselves to similar work.

In 1912 Dr. Mayor asked me to join him in an expedition to the Bahamas, and while there I came for the first time into contact with a large family of ground-dwelling mollusks known as Cerions. The natives call them peanut shells because they look a bit like peanuts. They vary in size from 1/3 of an inch to 1½ inches. The largest have a diameter of ¾ of an inch, so you see they are rather large objects. They are so abundant where they occur that I have picked up 4000 in a space 20 feet square. There is therefore no difficulty in getting material.

While in the Bahamas we secured many specimens because we wanted to see if there was any uniformity expressed in the different colonies for all the Cerions occur there in colonies. You sometimes find one colony separated from another by just a little swale which seems to be a sufficient barrier to keep them apart. I measured many of these shells to determine modes, to see if I might by the use of bimetric methods determine sub-species among certain groups. It was found that while you may have quite a range of variation in size in each colony, you do meet more or less definite modes.

It has been held that Cerions were the most easily changed organisms that could be imagined, that practically a breath of wind would affect growing individuals and thus make variations. A year of great humidity, it was believed, might pro-

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duce larger forms; while a year of dry conditions might produce dwarfed forms, etc. In fact they were looked upon more or less askance by systematists on account of the lack of definite information as to the stability of the races. We all admired Dr. Pillsbry's courage when he published his monograph on the group, and we likewise deplored Mr. Maynard's efforts for it seemed as if he had given a name to almost every accidental form expressed in the shell of individuals of each colony.

We deemed it wise to transport colonies to the Florida Keys in order to determine whether Cerion characteristics as expressed in the shell had a fixed status. By so doing we would subject them to a change in environment which would settle the stability question. We therefore gathered many thousands of two species. One species was taken from about the White House at the southeast corner of South Bight, and the other from King's Road, which is on the northeast corner of South Bight. The two places are separated by about two miles of water. So far as shell characters go I feel that if you photograph one and reduce it one-third the same specimen might serve as a figure of a specimen from the other group. It was this close resemblance that made me hesitate to use even a sub-specific name for these species in the earliest reports and you will find them referred to in the Year Book of the Carnegie Institution as the King's Road and White House type of *Cerion glans*.

The transported material was planted on the Florida Keys in colonies of 500 each. We though it well to try mass breeding first, for if we took only one pair accidents might happen to prevent the success of the experiment. A colony of 500 was planted on the Ragged Keys immediately south of Miami and from there on south to the Tortugas we put colonies on various Keys. You will recall that the Florida Keys extend over a long distance and have a varied flora and a varied temperature. The temperature sometimes goes down to freezing at Miami, while at the Tortugas it has never dropped below 48 degrees. We also have quite a range in humidity variation from the northern Keys to those of the Gulf.

When we started the experiment we believed that each year would yield at least one generation, and it was indeed

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a great surprise when we found that it required three years to produce it. The results, therefore, were obtained much more slowly than we had anticipated.

We alternated the two species experimented with, putting one on one Key and the other on an adjacent Key so that the two species should be subjected to practically the same set of environmental conditions. We also separated each generation into new colonies, thus preventing crossing with the parent stock.

Summing up the results so far obtained we find that the first generation of Florida born material presents no change in measurable shell characters. In other words the measurement of measurable characters in the first Florida born Cerions were the same as those of the parent stock. From a breeder's standpoint that was not remarkable. We know that the germplasm had received its impress in the Bahamas so we might expect to obtain no results in the first generation.

Two years ago a second generation was obtained and we were surprised when we measured the measurable characters to find it just like the material planted. It had bred true to type. The range of variation was not at all different from that of the Bahama material. This, then, was one thing gained; for it showed that changed environment, the thing that most people held responsible for the production of the various races, did not seem to be an operative factor in the first generation of Cerions. Usually, however, a response is obtained in the second generation, for here the germplasm becomes involved and it is here that the impress of the changed environment should show its effect upon the offspring. This generation, however, like the first showed the same stability of characters as the first generation of Florida born specimens. They bred true to type.

However, we obtained some other results much more significant than the above. On the Florida Keys we have another group of Cerions decidedly different from those of the Bahamas. It is a group that has been here for a very long time and is known as *Cerion incanum.* I believe that this too is a complex. For when the anatomy of the animals forming the various colonies will have been examined, we shall probably find that more than one species exists on the Florida Keys.

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In making our planting of Bahama mollusks on the Florida Keys we tried to avoid putting the Bahama species where the native species occurred. On one, Newfound Key, there were indications of the Florida species. But the 1909 hurricanes seemed to have wiped them out completely leaving only dead shells. Here we put a colony of 500 of *Cerion viaregis* because it seemed such a splendid place for them. We were greatly surprised when upon rounding up the Cerions on this Key (for we rounded them up annually and photographed and measured the new generation when mature) to find that there were some specimens which showed that something had happened.

Four specimens were found on one bush which showed unmistakable evidence that *Cerion viaregis* had crossed with *Cerion incanum*. For characters of both species were expressed in these shells. *Cerion viaregis* is strongly axially ribbed and more or less flecked with brown, and has the interior of the shell buff or light brown—while *Cerion incanum* is almost smooth, of different outline, and usually almost white, though at times vermiculated with pale brown. The four shells referred to above combined the characters of the two.

On a subsequent visit we found the place of planting simply swarming with Cerions. The mollusks, however, were neither *Cerion viaregis* nor *Cerion incanum* but presented what Dr. Dall long ago termed a state of flux, that is no two specimens were exactly alike. The range of variation not only presented all possible gradients from the one species to the other but included the production of entirely new forms which one not familiar with their history would unhesitatingly assign to entirely different groups of Cerion than those to which either parent belonged.

There are no end of interesting problems tied up in this experiment, not the least of which is the fact that we shall have to modify our idea about always producing sterile offspring when we cross widely unrelated species. In the present case it seems to have energized reproduction rather than retarded it for the place was swarming with individuals.

It is possible that these experiments may explain how fluxed conditions are produced. I am sure each of you can recall such cases in your own field, which may have been pro-

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duced in this manner. It is possible that from such fluxed elements new species may be produced by isolation and fixation.

This cross of *Cerion viaregis* and *Cerion incanum* was a great surprise to us, the more so since the two Bahama species which we had purposely mixed on one of the Keys absolutely refused to cross but have continued to breed true. These two we have since found to possess anatomical barriers responsible for this, and yet we are quite certain that they are very closely phylogenetically related.

A new set of experiments was started in 1919 but the hurricane of last August swept all of our cages to the sea. Next December, however, a new set of experiments will be begun in which we intend to carry out the following plan: Large cages 4 ft. x 6ft. x 3 ft., and small cages 2 ft. x 3 ft. x 3 ft. will be used. In the large cages 50 each of two species will be placed, while in the small cages only one of two species will be put. Of the small cages we shall have ten for each combination. Only adolescent mollusks will be used to make sure that fertilization has not taken place before they are placed in the cages. We intend to experiment with the following species:

Cerion viaregis from the Bahamas
Cerion casablanca from the Bahamas
Cerion incanum from the Florida Keys
Cerion uva from Curacao
Cerion crassilabris from Porto Rico.

The question to what extent this work on the Cerion throw light on bigger biological problems and to what extent does it throw light on the production of new species could best be determined if it were checked up by work of a similar nature in other fields. We hope, therefore, that work similar to ours may be undertaken out here. It could be done so readily by someone on the ground.

The Cerion work so far as it has gone is written up in the Bulletin recently published by the Carnegie Institution. Anyone wishing to do similar work should consult this paper and so far as possible work along parallel lines.

One thing interesting and somewhat unusual in our experiment is the fact that we actually know what material we started with. When one looks at much of the breeding experiments that have been made, one usually finds a complete indifference

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to the question of what the experimenter is breeding—a fact which has made it impossible to really understand what was at the bottom of the results obtained. It is to be hoped that in the future this point may receive the attention it really deserves so that it may be possible for any one to repeat the work and check up any point about which the least doubt may be presented.

Some of the recent results obtained in the breeding of Drosophyla and other organisms suggest parallel features to the Cerion work but unfortunately nothing definite seems to be known as to what has been combined in these experiments. It is therefore to be hoped if experiments with Achatinella, Amastra, Partula or Helicostyla are undertaken that a careful record will be kept of the species combined.

You may be interested to know that the distribution of Cerions is from Dutch Guiana to the Bahamas, Greater Antilles and the Florida Keys, one occurring upon Curacoa. We have not been able to find a single Cerion living on the shores of the Lesser Antilles. The center of distribution at present is in the Bahamas where, as I stated before, every swale separates a distinct form.

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PAPERS ON VOLCANOLOGY

THE PROGRAM OF EXPERIMENTAL VOLCANOLOGY

By T. A. Jaggar, Jr.

EXPERIMENTAL PROGRAM AS DEVELOPED IN HAWAII

By "experimental volcanology" is meant the study and measurement of live volcanic processes in the field and the investigation of these processes by the experimental method. The tradition of "experimental geology" is so woven about laboratory experiments imitative of geological processes, that it is well at the start to define the new volcanology as a field science. The writer's experience passed from descriptive geology to experimental geology, and from experimental geology to the field study of physical processes, and he is convinced by that experience that the whole future of geology, and its awakening to the dignity of being reckoned a quantitative science, depends on the progress of geophysics. By geophysics is meant the measured physics of the geoid, the processes of air and water, and the work of gravity, seismicity, magnetism and atomic energy through reactions in and on the terrestrial globe. The geophysical observatory now takes rank with the observatories of astronomy, and like them grows increasingly specialized. In volcano science we have to deal with description of events, quantitative measurement and pictorial record, charting and diagraming of changes, registration of seismicity, and experimental investigation of gases, waters, lavas, salts, sublimates, temperatures, viscosities, pressures and soundings. The volcano observatory must so coordinate its work in repose periods and its work during eruption as to be always busy and never hysterical.

The Hawaiian Volcano Observatory was proposed and planned eleven years ago, and began work in 1911 with temperature measurements and published weekly bulletins, accompanied by photographic illustrations and seismologic data dealing with the lava pit of Kilauea Volcano. From very modest beginnings it has grown a little, but it is still a very small establishment, owned by the Hawaiian Volcano Research Association, and operated by the United States Weather Bureau.

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The writer made the original plans and has fostered the tiny laboratory through its decade of vicissitudes of infancy, insisting on continuous publication, occasional experimentation, and ceaseless making of records visual, photographic, topographic, and seismometric. There are now twenty-five typed record books dealing with Kilauea alone, containing field notes, photographs and surveys, each on special sheets with printed headings for the respective purposes, and there are yet other books dealing with expeditions, seismometry and special experimental investigation. Mauna Loa has erupted three times during the interval, and from February, 1918, to the present time there has been increasing lava outflow from Halemaumau, the lava pit of Kilauea. This outflow culminated in January, 1920, by breaching the southwest flank of Kilauea mountain, and pouring floods of lava into the open desert country. These flows have been slowly progressing.

The motives of volcanology have been given current expression in the textbooks of Mercalli, von Wolff, Iddings, Schneider and Daly, and in the researches of such workers as Washington, Tempest, Anderson, Omori, Lacroix, Hovey, Brun, Friedlaender, Day and Shepherd, Perret, Angenheister, the Hawaiian Observatory staff, Maso, Malladra and Griggs. Dr. Branca of Berlin issued a circular a few years ago calling for opinions as to how volcanoes should be studied. The replies published were unhappy in showing general disregard on the part of geologists of the necessity for permanent volcano experiment stations. The letters advised making expeditions to study the result of eruptions after they were over, and suggested chemical and mineralogical study, and the collection of gases. The essentially historical viewpoint of the geologist was apparent, the men of science deeming volcano repose periods as of no interest. This attitude neglects the cumulative stresses which precede eruption, the seismic peculiarities of repose periods, the temperature and gas changes leading to a crisis, the seasonal controls of the rock tide, and the human factor as a matter of paramount importance at times of disaster. Moreover the expedition method does not place expert volcanologists at the scene of eruption when the culmination occurs. The Branca letters took no account of the fact that each volcanic system has some vent, like Stromboli, Kilauea, Asama or Tanna, where the lava column is always in evidence, where

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change is always measurable, where gases are always emerging and where the details of change in relation to passage of the seasons are unrecorded naturally and can never be reconstructed by study of geological effects.

The record of seasonal change, whether slow or rapid, is of economic importance in furnishing data for eruption forecasts. The record of volcanic earthquakes is of far-reaching importance in the promise afforded of settling the vexed question of the distinctive meaning of the word "tectonic." The records of tilt and tremor at a volcanic centrum, the measurements of elevation or subsidence, and the relations of these to times of paroxysmal eruption, promise to throw new light on isostatic compensation. The correlation of adjacent vents by day-to-day study will determine the interactions of solution, saturation, temperature and pressure in relation to tidal and meteorological controls. The record and collection of sulphates and kindred soluble salts at new lava fields will furnish quantitative data concerning the amount of substance which fresh magma loses through percolation of meteoric waters. The record and collection of iron oxides in different parts of new volcanic edifices, and the study of their formation during the congelation of lava, promise to illuminate the chemistry and dynamics of volcanism as effectually as the study of the gases. Temperature measurement, gas collection, and measurement of the radio-activity of the gases while fresh, are the most fundamental lines of investigation which can be attacked in the whole range of geophysics, and it is only at volcanoes that the observer may be persuaded that the gaseous emissions are deep-seated. All of these features change with the passage of time, rapidly at times of paroxysm, slowly at other times. The critical points of change are the indices of coming events.

The general outlook of volcanology has changed since 1900. It is no longer a branch of historical geology, its affiliations are with physics and engineering. However you may scoff at volcanic earthquakes, the fact remains that most of Milne's earthquake districts enclose volcanic systems. Whether causes or effects, the magma and its contained gases are there, the deep-seated isostatic compensation is there, the steep crustal flexures are there. The contracting nucleus perhaps is not there—Dutton

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abandoned contraction utterly[1] sixteen years ago—but heating and tumefying mechanisms are increasingly probable, and Darwin's generalization connecting volcanism with elevation has never been gainsaid. Great earthquakes are sporadic, cataclysmal, intractable. Volcanic systems are definitely placed within earthquake belts, they are permanent and more or less rhythmic in their activities, and earthquakes great and small occur on their flanks. Cartago lies at the foot of Irazu, Messina at the foot of Etna, Guatemala at the foot of Agua, Kagoshima at the foot of Sakurajima, Hilea at the foot of Mauna Loa; all of these were scenes of major earthquakes teleseismically recordable. Chili, Mexico, California, Alaska, Japan, Philippines, Java, New Zealand, Hawaii—circle the Pacific and voyage out to its center, in all of these places you find volcanoes *and* great earthquakes. Perhaps there is tectonicity—pardon the word—without magma underground, but the burden of proof weighs heavy on its advocates. There is certainly no volcanicity without earthquakes underground. Therefore I plead earnestly that volcano observatories be established as geophysical stations, to cover local seismometry and volcanology as well.

This plan suggests that by completely recording eruptions, tilts, tremors, local quakes and distant quakes at one station, we shall be registering the physical condition of magma, along with the fundamentals of seismology and perhaps isostasy. When our seismographs for local earthquakes reach such perfection that direction, distance and angle of emergence are all indicated, and those for teleseisms yield similar data along with evidence of the rigidity of the transmitting media underground as shown by the S waves, we shall find ourselves much better placed for correlating results if living near a live lava column. In this I am citing the experience of the Hawaiian Observatory, but our instruments are still far short of these ideals. In magma study the Geophysical Laboratory of Washington, by physico-chemical investigation of limited systems of elements, has established a sound and rational basis whereon workers in the field may rely. Matteuci in 1897 laid down a program of study for Vesuvius which in the main has been followed at the Hawaiian station, but we have not included geology and petrography. These would carry a small staff too far afield into the domain of structural

[1] "The contractional hypothesis is here regarded as being virtually destroyed by effective criticism, and in the form given it by Mallet as being simply an error." Earthquakes, by C. E. Dutton, 1904, p. 30.

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history and geological surveys, work which must be cared for by the federal Geological Survey. An observatory is concerned only with the history of present events, and the probabilities of future ones. At the Kilauea observatory the compilation of records and ordinary routine would keep the staff busy for years, even if the volcanoes showed not a glimmer of fire.

The Branca circular above referred to revealed a conception of active volcanoes which is still very common among men of science who view the subject as travellers and library students. They think of the volcano as an impossible field for continuous laboratory study. They think of it with distaste, coupled with a natural shrinking from places infernal in their seeming, where gases are hot and poisonous and frightful explosions are possible. Furthermore the dilemma of long repose periods makes it incomprehensible to the layman that a fixed observer should find anything at such times to keep him busy. It is as though the warrior said, "What use for a navy without war?" or the physician "What use studying health when my business is with disease?" or the astronomer "What use studying so slow a process as the orbital motion of binary stars?" The analogy with the astronomical treatment of eclipses should make geonomers ashamed that they have permitted the great crisis of Lassen's Peak in California to go by without continuous quantitative measurements. No observatory was established, not even a temporary one. No gases were collected, no photographs taken systematically, no pendulums were set up, tilt and tremor were not measured, no journal was kept, no temperatures were taken. The method of expeditions and specimens was applied. Was Lassen rising quaquaversally before the eruption? Did tremor accompany the tilts? Was there chlorine in the gas? Was the earthquake frequency at a maximum before, during or after the volcanic culminations? Was the intensity greatest in the intervals? What was the distribution of localized volcanic quaking? When did the seismo-volcanic curves of the entire eruptive period reach culmination? Was there a lunar monthly and a solar semiannual effect? Is there centripetal tilt now in the declining stages of the eruptions? Apparently we must wait another two hundred years and read the answers then.

When the Hawaiian observatory was first established there was no foreseeing what measurements would prove most important. All was obscure except that a lava column was dimly vis-

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ible and measurable, and that seismic events were taking place. After two or three very dull years, the tables of rising and falling lava, of atmospheric temperature, wind and rain, of lunar and solar maxima, of earthquakes, tilts and tremors, began to show correspondences; the collections of gases, measurements of lava temperature, photographs of the fume column, convectional streamings in the melt, rise of crags in the lava lakes, began to excite discussion and questionings. After two or three more years seasonal and rhythmic recurrences began to take shape; the lava rose and became accessible for soundings, for measurement of its thermal gradient, for collecting gases from the blisters on its surface, for photography of its flames, for study of the intense oxidation of the iron content. Next came overflows, differentiation into smooth and scoriaceous types, development of tunnels, secondary fusion in the tunnels, cooling of the tunnels, drip of aqueous solutions and deposit of great quantities of sulphates. In the course of this cycle leading to culmination in Kilauea, Mauna Loa broke into intense explosive and foaming outflow on three occasions, with sympathetic subsidences at Kilauea, setting at rest forever the much-mooted question of the supposed independence of the two vents. Finally Kilauea mountain split open along its southwestern rift zone, after the 1919 eruption of Mauna Loa had ceased, lava gushed forth from cracks in the open country and these flows are still in action in the summer of 1920. All of this was accompanied by seismic happenings which were consistent and instructive, and the whole series of events from 1913 to 1920 constituted a curve of rising volcanicity, fragment of a cycle which the future will explain.

From this experience a definite program of physical volcanology as an experimental science for this station has been evolved, consisting of:

(1) Volcanologic experiments,[2] development of instruments required for measuring and analyzing the physical and chemical peculiarities of volcanic magma and volcanic gases.

(2) Seismometric experiments,[3] development of instruments required for measuring and analyzing the

[2] T. A. Jaggar, Volcanologic Investigations at Kilauea, Amer. Jour. Sci., September, 1917, pp. 161-220, I pl., 22 figs.

[3] T. A. Jaggar, Seismometric Investigation of the Hawaiian Lava Column, Bull. Seis. Soc. Amer., December, 1920.

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physical peculiarities of the rock crust of the earth under a volcano observatory, and the movements of tilting, trembling and quaking which are distinctive of proximity to volcanic magma.

(3) Systematic and continuous mapping of craters, lava pools and lava flows, photographic records, and maintenance of a journal.[4] This furnishes volume-geodetic data for the ejectamenta in relation to the progress of gas emission and other thermal and chemical events. The experimental work of (1) and (2) furnish the tools and methods for gradual improvement of (3).

(4) Computation of volcanic energy available at a given vent. This is a thermo-dynamical problem wherein (1), (2) and (3) eventually should furnish the data of exothermic reactions, temperatures, conductivities, dimensions, assumptions as to radiation, and rate of effusion of magma.

The last item of the program is the ultimate goal of volcanology. Daly in 1909[5] estimated that the lava lake of Kilauea lost per second by conduction 4450 and by radiation 230,000 kilogram calories. Galitzin and others[6] have made some attempt to evaluate the energy of individual earthquakes. The resident observer soon becomes convinced that the available heat supply at a crater is limited, and the heat radiated for a given time is calculable, at least as to its order of magnitude. The earthquake swarms distributed over a volcanic system furnish another clue to the energy expenditure along the subterranean rifts. The three years of hot lava emissions 1918-20 on Hawaii may be comparable in total mechanical effort to the shorter explosive outbursts of the Kirishima-Sakurajima system in 1913-14. There is clearly a limit to the range of effects and bulk output which a single volcanic system can achieve during a single eruptive episode, and there is much similarity in the volume of separate volcanic outpourings. Some are slow and others are rapid, some pulverize their products and eject them to enormous heights in a short explosion while others liquefy them and flood the moun-

[4] Bull. Haw'n. Vol. Observatory, 1913-20 et seq.

[5] R. A. Daly, The Nature of Volcanic Action, Proc. Amer. Acad. Arts & Sciences, vol. 47, No. 3, pp. 72-73, 1911.

[6] O. Klotz, Earthquake of Feb. 18, 1911, Bull. Seis. Soc. Amer, V-4-206: Jour. Roy. Ast. Soc. Can., Nov. 1915, 428.

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tain slopes through year-long periods, but none is very small or very great compared with the dimensions of the earth crust.

The evaluation of these energy relations is of the utmost importance to humanity. On such computation depends the connection between geodesy and seismology on the one hand, and volcanology on the other. Problems of cosmogony, of the interior heterogeneity or homogeneity of the layers constituting the globe, of isostasy, even of astronomy are to be elucidated by such measured data. The engineer can advise concerning safety of volcanic neighborhoods only when he has quantitative estimates of what forces may bombard the structures which he erects. The mathematician may compute the dissipation or storage of energy which the present earth is accomplishing only when informed of the facts concerning the chemistry of the superficial layer. The true conditions discovered and measured with increasing precision at the volcano observatories, cannot work otherwise than to set at rest many of the doubts of theoretical geology, and to furnish many surprises concerning forces which have been time-honored in the older textbooks.

It may be objected that Kilauea is so exceptional in the fruitfulness of its volcanic field that no other land could develop such a program in the same decade. The Hawaiian observatory was proposed in 1909. Taking the decade 1909-1919 what do other Pacific lands show? Japan has had Tarumai, Usu, Kirishima, Sakurajima, Asama, Iwojima, Suwanose, Yakedake and other volcanoes in eruption; the Alaskan Peninsula has had Katmai and other eruptions; California has had Lassen; Salvador has had the San Salvador volcano; Costa Rica had an outbreak of Irazu; Samoa had the last three years of the Matavanu outpouring; New Zealand has had eruptions, with loss of life, at Waimangu, White island and Ngauruhoe; Tonga had Honga Hapai and Niuafou, volcanoes active in 1912 and 1913; the New Hebrides had the disastrous Ambrym eruption and Tanna is always active; the Philippines had Taal in 1911, Balusan in 1916 and 1918, and other eruptions; Java had the outbreaks of Raoeng and Kaloet, the latter disastrous, and probably others. I have no records of what has been happening in Mexico, South America, the Aleutians, Kamchatka, the Kurile islands, the Celébes Sea and the Mariannes, though very recently we have heard much of a Mexican disaster wherein earthquakes and eruptions were combined. Any of these lands can produce in a

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decade abundance of work for a volcano observatory, always providing that the station is placed near a crater which has an active record, and that it is equipped with facilities for making expeditions to other volcanoes of the same system. An investigator placed at Waimangu, Izalco or Lassen in 1909 would have rendered invaluable public service within the decade, and the excellent laboratories actually existing in Tokyo, Manila and Apia have certainly been kept busy.

ILLUSTRATIONS OF RESULTS ATTAINED IN HAWAII

Some results attained by nine years of work at the Hawaiian Observatory are summarized in the paragraphs which follow. These epitomize the conclusions of an article by the writer published in Bulletin of Seismological Society of America, December, 1920. The following definitions will serve to make intelligible the terms used:

Hypomagma is the under magma with gases in solution.

Pyromagma is the liquid or vesiculate lava of surface pools and flows at an active volcano.

Epimagma is the residue of pyromagma which has lost its gas completely, leaving a "dead" scoriaceous product.

Dermolith is smooth lava with a membrane or skin outside, and spherical vesicles.

Clastolith is scoriaceous lava with deformed vesicles.

Perilith is the confining wall of a live lava system, whether it bound fissures, or a crater, or a complex of both.

The Hawaiian Observatory, where the seismographs are mounted, is 22 miles nearly east of the high central crater of Mauna Loa. This crater is considered the main volcanic centrum for the Hawaiian volcanic system. A zone of rifts passes through this crater, different parts of which have emitted lava at different times, and it is the distance of this zone from the observatory which is spoken of in the following as "Mauna Loa distance." Kilauea mountain, where the observatory is placed, has other fault fractures and lava vents not so far away, and these are referred to in the mention of "shorter distance."

It should be understood that these results are not in any way believed to be final, they represent only rough reconnaissance of the gas problem, the oxidation problem, the seasonal effects of the crustal tide, and volcanic seismometry. I introduce them merely by way of illustration of the inter-

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esting possibilities revealed by compilation of various kinds of measurements.

LAVA COLUMN

1. The hypomagma, with reagent gases in solution, dominantly hydrogen, carbon compounds and sulphur, is the actuating medium for the phenomena of volcanism.

2. The pyromagma, vesiculated and heated by gases, is the fluent lava of volcanoes described as dermolithic, the pahoehoe of Hawaii. Gases escape from solution within it and react exothermally up to the time of congelation.

3. The epimagma is made by subaerial processes, where convectional stirring or flowage release gas completely, and the vesiculate residue solidifies in granular or efflorescent forms. These are described as clastolithic lava, the aa of Hawaii.

4. The bench magma of Halemaumau, substance of the mobile floors, crags and lake bottoms of the lava pools, is epimagma mixed with congealed pyromagma.

5 The effective structural unit in active volcanicity is the volcanic system, a rift complex, and the lava column is bounded by the perilith, the confining wall of the volcanic system.

6, The lava column is a foam bubbling more or less as gases are released by change of pressure, and more or less viscous as heated by gas reactions. Pressure may be increased and gas release restrained by its own dermal consolidation.

7. Oxidation of the iron through invasion of epimagmatic vesicles by air, while clastolithic lava is hot, is apparent in such lava, and may be a powerful exothermic agency in keeping such lava fluid.

8. There is a complicated crateral circulation maintained by convection; effervescing pyromagma rises and both its crusts and its epimagmatic residue sink; pyromagma maintains a tubular plexus in the mobile substance of the bench magma; this substance is itself in slow circulation under the weighting of overflows and the accretions of epimagma. The hypomagma beneath is sensitive to the pressure effects. There is an incessant deep flow of the under substance towards the region of minimum load.

9. Tumefaction in hypomagma is propagated in the directions of least loading wherever bubble pressure gains headway

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and releases new gas to the bubble form. Linear expansion in the perilith by gas heating may contribute to the surface evidence of tumescence.

SEISMIC EFFECTS

10. Underground magma is restrained by the perilith. Trigger release of pressure resides in the seasonal tides that pass through the rock crust of the globe. Slight stress changes affecting extensive perilithic belts may induce intense tumefying action which strains the volcanic edifice to the breaking point. Tilts, tremors, volcanic eruptions and earthquake swarms result.

11. Deep tumescence occasions simultaneous tilt and tremor, which act slowly through weeks preceding eruption.

12. At the Hawaiian Observatory east tilt precedes visible rising of lava by 18 days, and west tilt precedes sinking of lava by a like interval. The beginnings of rapid forced movements away from the volcanic centrum exhibit the most perfect accordance with the subsequent lava risings.

13. Allowing for diurnal temperature effects, which are measured and definite, the longer term tiltings resolve themselves into quasi-rhythmic decaying series of tilt waves, the series of quarterly, and the waves of monthly, period. These groupings suggest a solar and a lunar causation. The angular amount of the tiltings is excessive. The mean directions are away from and towards the volcanic centrum. The subsequent lava movements show similar rhythms.

14. Quick microtremor of one-fifth second period occurs in spasms which in frequency and amplitude vary directly with angular amounts of tilting. Harmonic microtremor of slower period also occurs and tends also to vary in amplitude with the tilting. The harmonic tremor has definite NE-SW direction of propagation.

15. Local earthquakes have maximum intensity and minimum frequency when the lava is lowest and the crater orifices are clogged. Maximum frequency and moderate intensity occur when the lava is flowing freely and effervescence in the crater pits is abundant.

16. In contrast to tilt and tremor, increased frequency of local earthquakes shows instantaneous agreement with times of rising lava and high lava culminations.

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17. The distances of local earthquake origins, judged by measurement of preliminary tremors, accord with Mauna Loa distance from station for Mauna Loa eruptions, and for Kilauea activities a much shorter distance is indicated. Slow subsidences of Kilauea lava culminate in earthquakes at Mauna Loa distances. Rapid subsidences of Kilauea lava usually follow earthquake swarms which began at Mauna Loa distances.

18. Earthquake frequency and lava culminations of rising both show tendency for crests to occur near equinox with some lag after equinox. The troughs appear to be reactions following the equinox effect.

19. In a rough way weekly earthquake frequency expresses the rate of movement of the lava column and the quasi-rhythmic monthly period.

INSTRUMENTAL EQUIPMENT

The following notes on instruments used at the Hawaiian station are from a memorandum furnished recently to the New Zealand government, and give some hint of the rough-and-ready methods which have characterized our work, at a station located in a forest remote from machine shops. The spirit of John Milne, who was always ready to experiment with the simplest tools and inexpensive materials, may well be cultivated by the volcanologists. The time is ripe for equipping central stations with good physical instruments and adequate laboratories. There is also much to be done by distributed stations and rough instruments in the hands of volunteers. One of the most pressing problems is the need for an instrument, as simple as a thermometer, purchasable anywhere, to show the occurrence and intensity of small earthquakes.

For measuring tilt, tremor, local earthquakes and distant earthquakes, at least two pairs of horizontal pendulums are necessary. For practical purposes optical registration is not necessary, though it may be desirable if vertical component registration and tilt-free records of teleseismic disturbances are sought. A series of seismometric experiments at the Hawaiian Observatory, by Dr. Arnold Romberg and the writer, demonstrated that for quick local movements smoked paper is better than bromide paper, as a very quick vibration may fail to register photographically. Horizontal pendulums are simple to construct, but the chronograph drum must

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have an equable rate and the transmission levers require some delicacy of adjustment.

The clinograph or tilt instrument consists of a light boom ten feet long suspended from a four-foot pier with a ten-pound weight near the end hanging in a bath of ordinary automobile oil. Upper and lower suspensions are both of steel piano wire. The writing stile at the end of the boom is pivoted directly to the boom without magnification levers. The tip rests on a drum surface that moves only one millimetre per hour, or about one inch per day. This motion need not be continuous and so may be actuated by the time clock contact, a magnet and ratchet taking effect once an hour. Three weeks or longer may easily be registered without re-smoking. The free period of the instrument at the Hawaiian station is seventy-two seconds, and the damping aperiodic. Tilt is measured from a fixed line of hour dots stamped on the sheet by an arm external to the drum carriage. The registered line shows the diurnal temperature tilt curve, and a longer period wandering in large measure volcanic. Two such instruments should be set up respectively in the meridian and at right angles to it. These instruments have proved unexpectedly serviceable for strong local shocks, the absence of magnification keeping the apparatus from derangement, and the maximum amplitude appearing directly on the tracing.

Tremor and local earthquakes require a magnification of 100 and a high speed drum moving at least thirty millimetres per minute. This means a change of sheets every twelve hours. In Hawaii we have rebuilt the Bosch 100-kg instruments, damping them with rigid vanes in sets of four immersed in oil tanks under the booms. The vanes lie in the oil edgewise to the directions of swing. The transmission from boom to magnifying lever is a light T bar with polished steel pins at each end of the cross-bar; these pins rest in watch jewels sunk in sockets in the boom and lever arms respectively. Guards of light spring brass prevent the T bar from being dislodged during a strongish shock. Quick local earthquakes with such apparatus register the P and S tremors very well when these are present, and the L waves are strong and smooth, without dotting. Time is marked every minute by electro-magnets which lift the stile-tip, the latter being of

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steel magnetized with polarity opposite to the lifting magnet. A gap in the scratched line results just as in the optical records. A pendulum period of from seven to ten seconds is quite long enough for local quakes. Volcanic tremor appears in the sheets of the Hawaiian record as fine undulations of line, best seen with a magnifier. We have arranged the N-S and E-W pendulums so that both stiles register on a single drum, showing both records side by side on the same sheet, and greatly reducing labor.

Notes on our experiments in teleseismic registration will be found in recent numbers of the Bulletin of the Seismological Society of America. The volcanologic instruments are chiefly thermometers, thermo-couples, cameras, transits, plane-tables, vacuum tubes, steel pipes and Seger cones, along with much apparatus devised as occasion demands, and so requiring shop tools. All of this material is the ordinary equipment of a physical laboratory, and each volcanic field requires experimental study in order to determine what is needed. The Bulletins issued by Professor Omori in Japan and by the Hawaiian Volcano Observatory[7] give evidence of what experimental adventures the workers have met with in two different fields. Incidentally ordinary meteorological records should be kept at a volcano station, in order to check the volcanic events against pressure, temperature, etc. Fairly accurate timekeeping is of course an essential, and if subsidiary stations are established, uniform timekeeping among the stations is imperative.

VOLCANOLOGIC ECONOMICS AND ENGINEERING

Mention has been made of the human side of the volcano problem and of the relation of volcanology to engineering. The importance of this has been abundantly illustrated in the disasters of the last twenty years. The Taal observatory and the Earthquake Investigation Committee of Japan both were created under the stimulus of disaster. There was demonstrated at Kagoshima in 1914 a marked advance in public education, a readiness to meet the trouble when it came, and the same may be said of the Guatemala earthquake. Loss of life was at a minimum in both cases. There is opportunity for much study and forethought in dealing with coming eruptions, with a view to preparation for disaster (or insurance), minimizing disaster (or protection), and re-

[7] See references in Nature, March 21, 1918, p. 44.

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covery from disaster (or reconstruction). Eruptions and earthquakes are not avoidable, but fires and weak buildings are; avenues of escape can be provided; prompt action can be assured; forewarnings are often definite; dangers from lava flow, dust, drought, panic, disease, famine, tornado, flood, sea wave, over-loading of roofs, lack of surgical supplies and all the manifold agencies that add to the terrors of an eruption may be foreseen and guarded against.

These matters have not usually been discussed at length in the published work of the geophysical investigators, but it seems to me that much good will be accomplished if the geophysicist in this respect will consider himself also an economist and an engineer. The financing of volcano observatories depends on the public interest. The public interest depends on the public education. The public safety and the reputation of geophysical science depend on the effectiveness of the observatory in educating the public. The geophysicist, through volcanoes and earthquakes, possesses a means of interesting the public which is very vital to the good people who reside in Kagoshima and San Francisco. Moreover, the growth of Pacific cities in a century has been phenomenal, and the cataclysm interval is often more than a century. The highest expression of the value of physical science is in successful forecast; this is true of astronomy and meteorology, and it is also true of geophysics. May we not, then, band ourselves together from east and west, pledged to guide the ambition of the young men towards the healthful, hardy and sometimes dangerous activities of the geophysical observatories, and take our motto from the Shinsai Yobo Chōsakwai—a committee for investigating the prevention of disaster.

DISCUSSION

MR. DAINGERFIELD: What meteorological instruments might be useful at Kilauea and Mauna Loa?

MR. JAGGAR: In this exceptional land with freezing temperature at night, hot desert conditions during the day and mobile material below, solar heating may cause expansion in the day and contraction at night. We want to know such things as the cooling effect and rainfall effects, that only meteorologists can tell. The top of Mauna Loa must be considered as having an extraordinary atmosphere. That peak nearly 14,000 feet high in the middle of the biggest ocean in the world, and on the highest mountain island in the world, is a unique place for a meteorological observatory. Meteorology and volcanology must work hand in hand; in many other countries there is close association between the two.

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The three divisions, meteorology first, seismology second, and volcanology third, should go together. At our station is an efficient meteorologist, Mr. Finch.

MR. COTTON: I wish to call attention to two points in Mr. Jaggar's paper: (1) In regard to the tilts, instruments installed in Australia to determine the tilting of the earth's crust which might arise in change of water levels show that very large tilts are seasonal in character. A tilt of five to ten seconds' range occurs from winter minimum to summer maximum. The period of the tilts lags several months behind the heat effects. The instruments are placed about 30 feet underground. The tilt records at Kilauea cover eight months, and a year's work is needed to see how the data compare. (2) In regard to the level of the lava, I understand that the crater has a maximum level at the equinox. Compressional and tangential stresses might be expected to result from the corporeal tides in the earth.

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THE CHEMISTRY OF THE PACIFIC VOLCANOES: THE LIMITATIONS OF OUR KNOWLEDGE

By Henry S. Washington

INTRODUCTION

Among the many problems that are presented by the Pacific Basin that of the chemistry of the lavas and other products of its volcanoes is one of the most fundamental and most important. This is so for several reasons. For one, the shape and the mode of activity of a volcano are greatly dependent on the chemical character of the magma that supplies it, and on the gases that it contains in solution of which a Pacific volcano—Kilauea—has given us our most exact knowledge.

Study, especially, chemical of the volcanic lava, forms one of the few sources of information as to what sort of material may lie beneath the immediate surface, and as to the physical conditions that may obtain in depth. This is of special importance when we deal with one of the great oceanic basins, such as is that of the Pacific, where, in the study of its floor, we are largely deprived of the stratigraphic and tectonic data that yield us so much knowledge in studying the land and masses.

In petrology, the science of rocks, furthermore, the igneous and volcanic rocks of the Pacific have been taken by Harker, Becke, and others, as typical of one of two great divisions of igneous rocks which are supposed, among other things, to be associated with different kinds of stresses to which the earth's crust has been subjected, whether of compression or of tension. For this reason alone, a point important for our knowledge of the rocks and structure of the earth, it is advisable to see whether the data available are sufficient, as to either quantity or quality, to justify such broad, far-reaching and fundamental generalizations as have been drawn from them.

To the petrologist, and, through him, to the geophysicist, geodesist, and other students of the composition and structure of the earth as a whole, this question of the composition of volcanic rocks is an important one, and is therefore one

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of those to which the attention of the members of the Pan-Pacific Conference may be directed.

It is my purpose in this brief note to endeavor to point out the extent of our data for knowledge of the chemistry of the volcanoes of the Pacific, to indicate the gaps in it and to suggest sound lines along which, possibly, the collection of further data and the study and systematic investigation of the whole subject may best be carried out. No effort is made to give a complete bibliography; that would necessitate much more time and space than are now possible. But some of the most important, and especially the most recent papers and those which contain most chemical data, will be cited. Many of these give references to previous literature, where further information may be obtained.

In two very interesting and suggestive papers, Prof. R. A. Daly[1] has laid before us the paucity of our knowledge, has discussed some of the problems presented, pointing out their importance, and urging very strongly the advisability of the systematic and complete scientific study and exploration of the Pacific basin, its volcanoes and other geological features. To these papers I am indebted for some of the facts presented here, and I can but join with him in urging the advisability of such investigations.

In considering the volcanoes of the Pacific it is to be noted that they are to be referred to two main groups, which seem to correspond with great tectonic and petrologic differences. The one group may be called the Circum-Pacific volcanoes, namely: those which are continental and which occur in a great circle around the Pacific. They extend from southern Chile, northward along the west coast of the two Americas, and thence through the Aleutian Islands, and Kamchatka down Japan and the Philippines to meet in the Moluccas the other great east and west volcanic belt. It may extend farther south to New Zealand. The other group comprises the Pacific volcanoes proper, or what may be called the Intro-Pacific volcanoes—those of Polynesia, Melanesia and Micronesia, with some detached islands. The Circum-Pacific volcanoes are arranged along a long curving, practically continuous line—the longest line of volcanoes on the earth, while the Intro-Pacific

[1] R. A. Daly, "Problems of the Pacific Islands," Am. Jour. Sci. XLI, pp. 153-186, 1916; and "Petrography of the Pacific Islands," Bull. Geol. Soc. Amer., 27, pp. 325-344, 1916.

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volcanoes are distinctly sporadic and in groups disconnected from each other, but mostly arranged in short zones, that have a general northwest-southeast trend. For some discussion of these more general features the reader may best be referred to Suess.[2]

There are very marked chemical differences between the lavas of the Circum-Pacific and the Intro-Pacific volcanoes. Without going into petrographical details, which would be out of place here, it may be said that the Circum-Pacific lavas are chiefly andesitic and show an excess of silica, while the Intro-Pacific lavas are dominantly basaltic and show a marked deficiency of silica. The former are higher in alkalies and alumina, while the latter are higher in magnesia and iron oxides. The general uniformity among the various Circum-Pacific lavas and the difference between these and those of the Intro-Pacific volcanoes, may be partially seen in Table 1, in which are given only the silica percentages and the position symbols in the quantitative classification of various regional or sub-regional averages that have been recently calculated by Dr. F. W. Clarke and myself.[3]

TABLE I—SILICA CONTENT OF LAVAS

	SiO_2	Symbol
Andes	60.86	(I)II.4.3.4.
Mexico and Central America	59.66	II.(4)5.3.4.
California	62.43	II.4.3.4.
Alaska	63.27	(I)II.4.3.4.
Kamchatka	61.55	....
Japan	61.93	II.4.3.(3)4.
New Zealand	58.25	II.(4)5.3.4.
Pacific Islands	50.06	II(III).5.3.4.

CHEMICAL CHARACTERS OF THE PACIFIC REGIONS

To the petrographer these figures and symbols are very significant and instructive, and even to the layman the difference in silica percentages between the Circum-Pacific and Intro-Pacific lavas is evident. The so-called "magmatic symbols" are more technical and less readily understandable; they show in brief form the general chemical characters, and even to the uninitiated there will be seen a general resemblance between those of the Circum-Pacific average lavas, as well as differences between them

[2] Suess, The Face of the Earth (English translation by Sollas), especially vol. 4, chapters ix, xii, xiii, xiv, and xvi, 1909.

[3] H. S. Washington, Jour. Franklin Inst., vol. 190, p. 757, 1920.

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and that of the Intro-Pacific Lavas.[4] These and other such observations form part of the quantitative chemical data on which is based a discussion of the generally recognized fact that the floors of the Pacific and other oceans are heavier than are the continental masses.

THE CIRCUM-PACIFIC VOLCANOES

We have a general idea of the broad characters of the long line of colossal *Andean volcanoes,* such as Aconcagua, Misti, Sangay, Cotopaxi, Antisana, Chimborazo, Pichincha, and many others; but of the chemistry and petrography of their lavas we have but very scanty detailed information. The volcanoes of only the northern part of this line have been investigated in anything approaching a systematic and adequate way by petrographers working on the material collected by Reiss and Stubel,[5] many years ago. To them we owe many petrographic descriptions, and about 37 chemical analyses, of fair quality. We have a good account of the rocks of the Patagonian Cordillera by Quensel,[6] who gives many good analyses of the intrusive rocks, with one or two of the lavas. Many years ago Iddings[7] showed the similarity between the chemical characters of the lavas of the Andes and those of the western United States. Apart from these there are only a very few papers that describe the Andean lavas.

The poverty of our knowledge may, perhaps, best be appreciated when it is stated that we have altogether only about 60 fairly trustworthy analyses from which to judge of the chemical characters of this line of the largest volcanoes on the globe, many of which are over 5,000 or 6,000 meters high, and the line itself extending over sixty degrees of latitude. The very height and bulk of these enormous masses, as well as their number, and the climatic and other conditions that surround them, render their proper study very difficult, and it will be, undoubtedly, many years before we can begin to consider our knowledge of them really satisfactory. We should, therefore, probably be thankful for the few data that we have.

[4] The New Zealand average includes analyses of many intrusive non-volcanic rocks, which tend to lower the silica percentage; but even thus it is distinctly higher than that of the Pacific islands.

[5] Reiss and Stubel, Geologische Studien in der Republik Colombia, Berlin, 1892-1899; Das Hochgebirge der Republik Ecuador, Berlin, 1892-1904. Cf, A. Stubel, Die Vulkanberge von Ecuador, p. 28-30, Berlin, 1897.

[6] P. Quensel, Bull. Geol. Inst. Upsala, vol. 11, p. 1, 1911.

[7] J. P. Iddings, Jour. Geol., vol. 1, p. 164, 1893.

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Forming, as they do, one of the greatest and most important volcanic zones on the earth, much more attention should be paid to the Andean volcanoes than has been paid in the past. We should know much more, and in much more detail, of their size, their structure, their activity, the variety and succession, and the petrographical and chemical characters, of their lavas, the characters of the pedestals on which they rest, their structures and relations to the volcanoes, and many other matters concerning them.

It may be suggested that American mining and civil engineers, many of whom are now, and in the future will be, working in this region, might make efforts to collect the igneous rocks, volcanic and others, with such notes as may be possible, and turn the material in to some central or home institution, (such as the U. S. National Museum, where it may be available for proper study and chemical analysis. Such collections would involve little time or labor—very little as compared with the unquestionably valuable results thus made possible in the accumulation of volcanologic and petrologic knowledge of this scientifically important and but little known part of the earth.

We have comparatively little information regarding the *Central American* volcanoes, such as Fuego, Izalco, Coseguina, Masaya, and Irazu, and still less as to the chemistry of their lavas. It seems scarcely necessary to give references here, as the few papers that have been written are short. Among them all, we have about one-half dozen fair to good analyses, of Central American lavas, with 22 of lavas and other igneous rocks from Panama and the Canal Zone, which have been published but not yet described petrographically.[8]

Of the *Mexican* volcanoes our knowledge is almost as limited. And it is to be remembered that the Mexican rocks include, not only lavas of such first—or second—magnitude volcanoes as Popocatepetl, Iztaccihuatl, Orizaba, and Colima, but very extensive, thick, and widespread flows of rhyolite and basalt. For Mexico there are available only twenty to twenty-five usable analyses.[9] Though these, with a considerable body of

[8] F. W. Clarke, U. S. G. S., Bull. 591, pp. 213-215; H. S. Washington, U. S. G. S., Prof. Paper 99, 1917.

[9] Felix and Lenk, Beitraege zur Geologie und Palaeontologie der Republik Mexico, Leipzig, 1889-1899; F. N. Guild, Amer. Jour. Sci., vol. 22, p. 159, 1906, E. Ordonez. Cong. Geol. Internat., guide, 11, 1906, G. I. Finlay, Ann. N. Y. Acad. Sci., vol. 14, 1903. There are few analyses of Mexican lavas outside of these four papers.

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petrographic descriptions, are sufficient to give us a general idea of their main chemical characters, we have not yet sufficient data to enable us to solve the various petrological and volcanological problems that the Mexican volcanoes offer. Of the volcanoes and volcanic rocks of Lower California we know next to nothing.

When we come to the Circum-Pacific volcanoes of the *western United States*, such as Lassen, Shasta, Rainier, Hood, Baker, and others of less magnitude, we are in much better position, thanks to the labors of the geologists and chemists of the United States Geological Survey, and others, and it may be said that we have a very fairly adequate idea of their petrography and chemistry.[10] There are at least one hundred analyses of these lavas, nearly all of good to excellent quality. Indeed it may be said that chemically the lavas of some of these volcanoes are among the best known of all volcanoes, with possibly a few exceptions, such as Vesuvius and Pelee. Mounts Lassen and Shasta, for example, are far better known chemically than are Kilauea, or any of the other Hawaiian volcanoes, Fuji-san, or, indeed, any Japanese or Intro-Pacific volcano.

Much, however, still remains to be done in the correlation of this mass of chemical data with the petrography of the lavas, the succession of the various kinds, the structures of the volcanoes, etc. It may be permitted to suggest that the U. S. Geological Survey, in the interests of volcanology, and especially of Pacific volcanology, undertake the monographic treatment of these volcanoes, utilizing thus the chemical and petrographical data that have been accumulated, for which purpose eventually they were collected. The occasion would serve to look into the old records, so as to trace back, if it be possible, the reported volcanic activity in the past, which might very probably throw light on the possibility of their recrudescence. The recent activity, or pseudo-activity of Lassen, has made this a matter of some public interest.

In *Canada* north of the State of Washington, extending along the Pacific Coast as far as Alaska, we find a long gap in which, so far as we know with certainty, no active or recently extinct volcanoes occur. Our knowledge of this stretch of coast

[10] Nothing approaching a complete bibliography can be given here; it is far too extensive. For many analyses, see F. W. Clarke, U. S. Geol. Survey, Bull. 591, pp. 166-205, 1915; also H. S. Washington, U. S. Geol. Survey, Prof. Paper 99, 1917. These give most of the analyses.

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is, however, very meager, but, as Russell[11] says, "It is scarcely to be expected that the volcanic belt * * * * * * * ends abruptly at the international boundary and begins again in Alaska." Here, obviously, is a gap in our knowledge of the Circum-Pacific volcanic zone that demands study in the near future.

Of the *Alaskan* volcanoes, which are confined to the southwest coast and the Aleutian Islands, we have some knowledge; at least as to their general characters. But, as elsewhere, this is inadequate. There have been published about one dozen analyses of their lavas, especially of St. Augustine, Bogosloff, and Katmai. These have been made by the chemists of the U. S. Geological Survey. In addition, but as yet unpublished, many analyses have been made of lavas and other products of Katmai, by Drs. Allen, Fenner, and Zies, of the Geophysical Laboratory, the material having been collected on their trip to the volcano in 1919. It would be advisable to have more analyses from the other Alaskan volcanoes and, incidentally, it may be mentioned that the rocks of the Pribiloff Islands seem never to have been investigated, though opportunities to collect them are many.

Coming round to the west coast of the Pacific, we have but very slight knowledge of the extreme eastern portion of Siberia. South of this, however, we know something of the volcanoes and their lavas on the peninsula of *Kamchatka;* this is mainly through the work of Bogdanovich,[12] to whom we are indebted for ten fairly good analyses. We also have a slight knowledge of the small volcanic group of the Commander Islands, in Bering Sea, and their rocks,[13] with a few analyses.

The *Japanese* volcanoes have been studied by the geologists of Japan with their usual intelligent assiduity, and the results are embodied in numerous papers, for the most part in the Journal of Science, Tokyo University, and in the Science Reports of Tohoku University. There are also many papers published in the Bulletin of the Japanese Geological Society. Prof. S. Kozu has published a valuable series of papers on

[11] I. C. Russell, Volcanoes of North America, New York, p. 266, 1897. The information collected by the Canadian Geological Survey would seem to indicate the absence of active or recently extinct volcanoes along this stretch of the Pacific Coast.

[12] Bogdanovich, Peterm. Mitth., vol. 50, 1904.

[13] Z. Starzynski and W. Zydmuntonska, Bull. Acad. Sci. Cracow 1912; J. Morozewicz, Mem. Com. Geol. Russ., No. 72, 1912.

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Japanese lavas, with many good analyses, in the Journal of Geology (Vols. XIX–XXI, 1911-913). There is also a series of excellent analyses of Japanese lavas made by E. W. Morley and published by Iddings with brief petrographical notes.[14]

From these analyses we have a very fair knowledge of the Japanese lavas. It may be said, that while we know from Kozu's studies, for example, that there are some alkaline types, yet, on the whole, the lavas of the Japanese volcanoes are remarkably constant in chemical composition: there would seem to be less variation among them than in almost any other volcanic district on the earth. It may also be of interest to mention the fact, which is apparently little known, that the lavas of the Japanese volcanoes show a very remarkable chemical similarity with those of the Antillean volcanoes, espescially Pelee and the Soufrières of Guadeloupe and St. Vincent.

Of the extensions of the Japanese volcanoes down the Riu Kiu group and southeastward to Bonin we have little or no chemical knowledge, the few analyses available being of very poor quality.

Of the chemistry of the lavas of the *Philippine Islands* we know but little, in spite of our twenty years occupation, though the chemists of the Mining Bureau have done something to describe them, in the midst of more pressing duties, chiefly in the Annual Reports of the Mining Bureau and in the Philippine Journal of Science. We have also a set of excellent analyses of Philippine rocks by Morley.[15] It might be suggested that, as we know very little of the important volcanoes of the Philippines, especially Taal and Mayon, it would be of great value if these volcanoes were treated monographically, both as to their volcanic structure and activity and as to their petrography and chemistry.

We may pass by here, as not belonging properly to the Pacific Basin the many volcanoes of Sumatra, Java, Celebes,

[14] Iddings and Morley, Proc. Natl. Acad. Sci., vol. 2, p. 452, 1916. It is impossible here to give a bibliography of the various Japanese papers. Nearly all the analyses will be found in: Iddings, Igneous Rocks, vol. 2, 1913; and in Washington, U. S. G. S., Prof. Paper 99, 1917. It may be permitted to express regret that much information regarding Japanese volcanoes is published only in Japanese, and is thus quite lost to the outside world.

[15] Iddings, Philippine Jour. Sci., vol 5, p. 155, 1919; and Iddings and Morley, Proc. Natl. Acad. Sci., vol. 2, p. 531, 1916.

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Borneo and the other islands of Dutch East Indies. There is a very considerable body of fairly good chemical work that has been done on their lavas, chiefly by Dutch chemists, the references to which need not be cited here. We have also a very considerable number of excellent analyses, published by Iddings and Morley,[16] and unfortunately interrupted by the death of the former.

Of the lavas of the *Moluccas* we know but little, practically nothing, for instance, of those of the large islands of Halmahera and Ceram, though we have a few analyses of lavas of Flores and Timor, including four excellent analyses of rocks of Timor made by Morley for Iddings. Of the volcanoes of the large, continental island of *Papua* (New Guinea) we know hardly anything, and have but four fair analyses of their rocks. As this large island is tectonically of great importance to our knowledge of the western Pacific, it is to be hoped that we shall have additions to our knowledge of its rocks, chemical and otherwise, in the future.

The chemistry and petrography of the lavas and other igneous rocks of eastern Australia (Queensland, New South Wales, and Victoria), of Tasmania, and of New Zealand, are very well known through the publication of many petrographical descriptions and excellent chemical analyses, by the various petrologists and chemists of those countries. The bibliography is so very extensive that it would be quite impracticable to give it here, but the great majority of the analyses will be found in Prof. Paper 99 of the U. S. G. S., with many references to the literature. It is obvious that we find in this extreme southwest and south Circum-Pacific region a distinct change in the chemical characters of the magma, apparently with some affinities toward the Intro-Pacific rocks.

INTRO-PACIFIC VOLCANOES

According to Daly's estimate[17] the area covered by the various Intro-Pacific islands, including detached ones, is about 75,000 square miles, of which nearly one-half is embraced by a dozen of the largest islands. It may be of interest to put on record Daly's table as given in the paper cited in the Proceedings of the Conference.

[16] Iddings and Morley, Jour. Geol., vol. 23, p. 231, 1915; Proc. Natl. Acad. Sci., vol. 3, p. 105 and 592, 1917.

[17] A. Daly, Amer. Jour. Sci., vol. 41, p. 158, 1916.

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TABLE II—AREAS OF PACIFIC ISLANDS

Group—	Square kilometers	Square miles
Pelew	503	194
Bonin and neighboring islands	110	42
Mariana	1,140	440
Caroline	1,450	560
Marshall	410	159
Hawaiian	17,008	6,566
Fanning (group)	668	258
D'Entrecasteaux	3,145	1,214
Louisiade	2,200	850
New Caledonia	16,920	6,528
Loyalty	2,743	1,059
Kermadec	33	13
Bismarck (including Admiralty Islands)	47,100	18,184
Solomon	43,900	16,952
Santa Cruz	938	362
New Hebrides	13,227	5,107
Fiji	20,837	8,045
Tonga	997	385
Gilbert	430	166
Ellice	37	14
Samoa	2,787	1,076
Cook (Hervey)	368	142
Austral (Tubuai)	286	111
Tokelau (Union)	14	5
Phoenix	42	16
Manihili	137	53
Society	1,650	637
Paumotu (Tuamotu)	978	378
Marquesas	1,274	492
Easter and Sala y Gomez Islands	122	47
Cocos	33	13
Galapagos	7,643	2,942
Juan Fernandez (group)	187	72
	189,317	73,092

In the following summary we shall confine our attention to those islands made up wholly or partially of volcanic rocks, some of them continental, and shall neglect the purely coralline or other limestone islands.

It may be said at the outset that our knowledge of the chemistry of the Intro-Pacific volcanic islands is not only far from complete, but is not even approximately satisfactory. Indeed, it is of the most fragmentary character—here and there an island or a volcano fairly well known, but not a single group completely known as to all its component islands, and many of the islands and groups (probably most of the islands) almost or quite unknown or not even partially investigated.

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The general character of the Pacific lavas is commonly supposed to be "basaltic." In a general way, this is almost certainly true. But, speaking petrographically, a dense, black rock that is commonly called a "basalt," may be of very varied character, mineralogical and chemical. And we are beginning to find out, from the very slight and scattered studies that have been made, that, not only are many of the "basalts" of the islands not true basalts but rocks of much more alkaline character, but also that the occurrences of trachytes and other alkalic, non-basaltic rocks are much more numerous and widespread than was thought up to a very few years ago.

Lacroix justly says, at the conclusion of his paper on the rocks of Tahiti cited below: "Il me paraît donc vraisemblable que l'étude attentive des roches volcaniques du Pacifique nous ménage des surprises pour l'avenir et que beaucoup de celles qui, comme les basaltes de Tahiti, considérées individuellement et *sans étude chimique* [italics mine] semblaient devoir être rapportées à une série calcique (pacifique), se rattacheront plus ou moins directement à la série alcaline (atlantique) que je viens d'étudier."

The general petrology of the Intro-Pacific volcanic islands is discussed more or less briefly by Lacroix,[18] Marshall[19] and Iddings[20] and is touched on by Daly[21] in the two papers mentioned above. It is noteworthy that all these, as well as other authors, point out with more or less emphasis the paucity of our knowledge. A general, but brief, survey of the petrography of the Pacific Ocean, giving a number of analyses and references, is given by Iddings in his Igneous Rocks (vol. 2, p. 648-657), and many analyses (up to 1914) and references will be found in United States Geological Survey Professional Paper 99. A general geologic description is given by Marshall in his Oceania, 1911. In the following pages only the more important and most recent papers will be mentioned, and especially those that are devoted to the chemistry of the lavas and which contain analyses. Many of them contain references to previous literature. It should be noted that the in-

[18] A. Lacroix, Bull. Soc. Geol. France, vol. 10, p. 91, 1910; C. R. Acad. Sci., vol. 151, p. 121, 1910.

[19] P. Marshall, Trans. N. Z. Inst., vol. 47, p. 361, 1915.

[20] J. P. Iddings, Proc. Natl. Acad. Sci., vol. 2, p. 413, 1916.

[21] R. A. Daly, Amer. Jour. Sci., vol. 41, p. 153, 1916; Bull. Geol. Soc. Amer., vol. 27, p. 325, 1916. (Daly's bibliography is not complete.)

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tention here is not to discuss the petrology or chemistry of the islands, but simply to point out very briefly the amount and character of our data for the various groups, and to emphasize the need of much greater extension of our knowledge.

Let us begin with the *Hawaiian islands*. The chemical and petrological data for Hawaii to 1915 have been assembled and ably discussed by Cross in his well-known paper[22] "The Lavas of Hawaii." He also gives a complete biliography up to 1915. It appears from this that including the new analyses published by Cross, there are but 43 usable analyses of the Hawaiian lavas so far published, as none published since 1915 are known to me. Of these 26 are good and 17 are poor. As might be expected, the most attention has been paid to the lavas of Hawaii, this island being represented by 29 analyses; of these 22 (6 good and 16 poor) are of lavas of Kilauea, 2 of Mauna Kea (both good), 2 of Mauna Loa (1 good and 1 poor), 2 (fair) of Kohala, and 1 (good) of Hualalai. There are only 6 (fair to good) of the lavas of Oahu, only 4 each of those of Maui and Kauai (all good), and none at all of those of Molokai, Lanai, or the smaller islands.

When we consider the importance of this group for our knowledge of the petrology and volcanism of the Pacific, the enormous size of some of the volcanoes, and the variety among the lavas shown by the few analyses available, as brought out by Cross, it is abundantly clear that the data at hand are sadly inadequate. That the great volcanoes of Loa and Hualalai should be represented by but one good analysis each, and Kea (the highest volcano in the Pacific) by only two analyses, reveals a most lamentable state of affairs. The data, even backed up by petrographic study, are clearly quite insufficient for proper generalization.

It may be of interest to the members of the Pan-Pacific Conference to state, in connection with the study of the Hawaiian lavas, that I am engaged in making a long series of analyses of them (25 having been completed at the time of writing), with the aim of making as complete a chemical study as may be possible of the lavas of the whole group. Some of the material was collected by me during and after

[22] W. Cross, U. S. Geol. Survey Prof. Paper 88, 1915.

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the Conference, but for the greater part of it I am indebted to the kindness and generosity of others, especially Sidney Powers, Whitman Cross, J. Allan Thomson, R. A. Daly, F. H. Daingerfield, H. S. Palmer, and W. O. Clark. The results of the study will appear in a series of several short papers, to be followed by a monograph on the Petrology of the Hawaiian Islands.

As belonging to the chemistry of the Pacific volcanoes, though not strictly petrological, mention should be made of the well-known researches of Day and Shepherd[23] on the gases of Kilauea, which have been of such importance to the study of volcanoes and their activity. Dr. Shepherd is at present engaged with further study of these, on samples collected by Dr. Jaggar, and has recently published two papers on the subject.[24] This is an investigation that has yielded rich, and promises to yield richer, results and its continuation is one of the most promising of Pacific volcanological subjects.

The *Society Islands* are better known chemically than are the Hawaiian islands, thanks to the work of Lacroix, Iddings, and Marshall.[25] Of the lavas of these islands we have, altogether, 47 analyses, all of good quality; these include 15 made by Pisani for Lacroix, 2 by Marshall, and 30 made by Morley, Foote, and by me for Iddings. The great majority are of rocks from Tahiti, but the islands of Raiatea, Moorea, Huahine, Tahaa, and Bora-Bora are represented among the analyses published by Iddings. It is of interest to note that the so-called "granite," found by Ellis on Bora-Bora, and thought to indicate a continental origin for this island, is shown by Lacroix to be a dolerite[26] (basalt), that is, a lava and not an intrusive rock. What Iddings[27] says of the rocks of Bora-Bora and Tahaa is quite confirmatory of this. As Lacroix says: "Ainsi s'evanouit le legende du granite des iles de la Societé." Granular (plutonic) igneous rocks,

[23] Day and Shepherd; Bull. Geol. Soc. Amer., vol. 24, p. 573, 1912; C. R. Acad. Sci., vol. 157, p. 1027, 1913.

[24] E S. Shepherd; Bull. Haw. Volc. Obs., vol. 7, p. 94, 1919, and ditto, vol. 8, p. 65, 1920 (Mauna Loa). (I am informed by Dr. Shepherd that another paper on the gases of Kilauea is to appear shortly.)

[25] A. Lacroix, Bull. Soc. Geol. France, vol. 10, p. 91, 1910; and C. R. Acad. Sci., vol. 151, p. 121, 1910. Iddings and Morley, Proc. Natl. Acad. Sci., vol. 4, p. 110, 1918; P. Marshall, Trans. N. Z. Inst., vol. 47, p. 361, 1916; and vol. 46, p. 281, 1914.

[26] Lacroix, Bull. Soc. Geol. France, 1916, p. 178.

[27] J. P. Iddings, Proc. Natl. Acad. Sci., vol. 4, p. 112, 1918.

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which seem to belong to the core of the volcano, occur on Tahiti, but very little has been written as to their relations. These islands promise results of great interest and demand much more general and detailed investigation.

The *Samoan Islands* are much less well known. Though we have several papers on their geology and volcanology, we have few petrographic descriptions, and ten analyses,[28] the only good ones being those published by Jensen and Klautsch. The analyses published by Weber are especially disappointing because, though he had at his disposal the very considerable material collected by Friedlander, only seven poor analyses were made for him by Hobein, in none of which were the two oxides of iron determined, in only one the titanium, and in none of them the minor constituents. It appears that Iddings did not visit the Samoan Islands and had no analyses made of their rocks. They were visited by Prof. J. Allan Thomson, on his return from the conference, and he has very kindly offered to send me for analysis representative specimens, of the rocks collected by him.

Of the rocks of the *Fiji Islands* we have but eleven analyses, all good, one by Stoddard and Mawson[29] and ten by Foye[30]; though there are several good papers on their petrography,[31] which also discuss their continental relations. Much more work remains to be done on the rocks of this important group.

Of the *Hervey* or *Cook Islands* much the same can be said, as we seem to have but one analysis of the rocks (Rarotonga) and but two short petrographic papers.[32] These islands would seem to be especially worthy of study, as the rocks, at least of Rarotonga and Aitutaki, are shown by microscopic examination and chemical analyses to be very high

[28] F. Möhle, Neues Jahrb., Beil. Band, XV, p. 93, 1902 (no analyses); H. I. Jensen, Proc. Linn. Soc. N. S. W., vol. 31, p. 641, 1906, and vol. 32, p. 706, 1908; M. Weber, Abh. Byaer. Akad. Wiss., vol. 24, p. 290, 1909; I. Friedlander, Abh. Bayer. Akad. Wiss., vol. 24, p. 509, 1910 (no analyses); A. Klautsch, Jahrb. Geol. Land-Anst., vol. 27, 1910.

[29] In W. G. Woolnough, Proc. Linn. Soc. N. S. W., vol. 28, p. 520, 1909.

[30] W. G. Foye, Proc. Am. Acad. Arts & Sci., vol. 54, p. 142, 1918.

[31] A. S. Eakle, Proc. Am. Acad., vol. 34, p. 581, 1899; W. G. Woolnough, Proc. Linn. Soc. N. S. W., vol. 28, p. 457, 1903, and ditto vol. 32, p. 431, H. B. Guppy, Observations of a Naturalist in the Pacific, vol. 1, London, 1903.

[32] P. Marshall, Trans. N. Z. Inst., vol. 41, p. 98, 1909; ditto, vol. 42, 1910.

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in soda and far from being typical basalts, though they would be commonly called "basalts."

Of the *Austral* (Tubuai) *Islands* we likewise know very little, there being few recent papers concerning their petrology[33] and no analyses representing their rocks. The same may be said of the neighboring Gambier Islands, of the rocks of which we have but one analysis,[34] and a few notes on some specimens from Pitcairn Island.[35]

The *New Hebrides* are better known, as we have some good descriptions of their geology, of recent eruptions of Ambrym, and of their rocks, with six good and two poor analyses of their rocks.[36] The latest eruption of the volcano of Ambrym has been very graphically described in the last paper cited.

The *Caroline*,[37] *Mariana*,[38] and the *Bismarck*[39] groups are very slightly known, there being but about half a dozen analyses of the rocks of the first two, (none of Guam) and three of those of the last. Of the large island of *Papua* (New Guinea) we also know but little, either petrographically or chemically, there being but four analyses of rocks from this island.

On the rocks of *New Caledonia* there is considerable literature, which is almost wholly devoted to the nickel occurrences of the island and the mining operations. Lacroix,[40] however, gives us nine good analyses.

As to the other islands of the central and western Pacific—the Marshall, Louisiade, Solomon, Marquesas, Santa Cruz,

[33] P. Marshall, Trans. N. Z. Inst., vol. 46, p. 282, 1914; ditto, vol. 50, p. 278, 1918.

[34] A. Lacroix, C. R. Acad. Sci., vol. 163, p. 181, 1916.

[35] M. Levy, C. R. Acad. Sci., 141, p. 895, 1905; and P. Marshall, Trans. N. Z. Inst., vol. 50, p. 279, 1918.

[36] A. Liversidge, Jour. R. Soc. N. S. W., vol. 20, p. 236, 1887; D. Mawson, Proc. Linn. Soc. N. S. W., vol. 30, p. 470, 1905; A. Lacroix, C. R. Acad. Sci., vol. 159, p. 489, 1914; P. Marshall, Trans. N. Z. Inst., vol. 47, p. 387, 1915; G. W. Card, Rec. Geol. Surv. N. S. W., vol. 9, p. 134, 1916; Frater and Gregory, Geol. Mag., 1917, pp. 496 and 529.

[37] E. Kaiser, Zsch. deutsch. geol. Ges., vol. 54, p. 62, 1902; Jahrb. Preus. Geol. Landesanst., vol. 24, p. 91, 1904.

[38] E. Lehmann, Tsch. Min. Pet. Mitth., vol. 27, p. 181, 1908.

[39] S. Richarz, Neues Jahrb., Beil. Bd., 29, p. 406, 1910.

[40] A. Lacroix, C. R. Acad. Sci., vol. 152, p. 816, 1911. Cf. F. D. Power, Proc. Inst. Min. & Metal., vol. 8, 1900; this contains some rock descriptions (no analyses) by Card, and a good bibliography. Cf. Miller & Knight, Nickel Deposits, Toronto, p. 234, 1917.

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Tonga and, other volcanic islands or groups—it may be said that we have but the most scanty information or practically none at all, and apparently no analyses representing their rocks.

Of the petrology of the islands near the west coast of South America we have little information. Representing the otherwise fairly well-known Galapagos Islands we have but one poor analysis,[41] and but one, and that of a badly decomposed rock, from Clipperton.[42] Of the rocks of *Easter Island* (Rapanui) and of *Sala-y-Gomez* we have no analyses, only a few somewhat doubtful statements based on inadequate petrographical study. The *Juan Fernandez* group is fairly well known through a study by Quensel,[43] who describes its geology and petrography, with three good analyses of the lavas of Masafuera, but none of those of Masatierra.

From the above brief and hasty survey it will, I think, be obvious that our knowledge of the chemistry and petrography of the Intro-Pacific volcanoes is lamentably incomplete. Representing the rocks of the volcanoes of an area that amounts to about one-fourth of the earth's surface—rocks and volcanoes that present problems of very great interest and importance for study of the materials and constitution of the earth—we have only a meager 130 analyses. Of these, about 100 represent only three island groups, and a very considerable proportion of these analyses are either of poor or, at best, of but fair quality. Of the best known groups—the Hawaiian, Society, and Samoan Islands—we have little more than glimpses of the composition of their rocks; of the others but tantalizingly few data, or none at all. From the little that is vouchsafed us, it is true, we know enough to make, with some degree of security, a few general statements—knowledge which only serves to whet our appetite for more, and for more detailed knowledge.

There is much (how much we do not know) more variety in the chemical and mineralogical characters of the Intro-Pacific rocks than was thought not many years ago, and the collections and studies of each year strengthen this belief. In this variety they are in striking contrast with the Circum-Pacific volcanoes, which show a much greater uniformity all

[41] G. P. Merrill, Bull. Mus. Comp. Zoöl., vol. 16, p. 237, 1893.
[42] J. J. H. Teall, Q. Jour. Geol. Soc., vol. 44, p. 230, 1898.
[43] P. D. Quensel, Bull. Geol. Inst. Upsala, vol. 11, p. 252, 1912.

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around the great volcanic circle. In average composition the circumferential and internal portions of the Pacific Basin show very great and striking differences. It is clear now, largely through the labors of Lacroix, Marshall, Mawson, Woolnough, Jensen, Iddings, and Cross, meager as our data are, that, although the Intro-Pacific lavas are probably dominantly basaltic, yet that there is an abundance of very alkalic types. The distriubtion of these throughout the area is a matter that demands much more acquaintance with the rocks of the region; but evidence is accumulating that the Intro-Pacific rocks do not represent a broad, general group (the so-called "Pacific"), which has been supposed to be of essentially basaltic character, and contrasted with another decidedly alkalic group, the so-called "Atlantic." The differences between these two supposititious rock families are supposed to be connected with the two main types of stress in the earth's crust whether tangential or radial, as they are exhibited by the coastal and other structural features of the two oceans.

We cannot go into this and other such matters here, but the mention of this one will, perhaps, suffice to give some idea of the possible bearings of study of the chemistry of the Pacific volcanoes on earth problems and of its consequent importance, and thus serve to emphasize the paucity of our knowledge and the great need for further and more detailed work in the region.

COLLECTION OF SPECIMENS

A few words may be devoted to brief discussion of the practical problem of obtaining the specimens and other data so much needed for the enlargement of our knowledge. From what has been said, it is fairly obvious that a very widespread and representative collection should be made, from as many groups, and as many of their constituent islands, as possible. Furthermore it will be necessary that these specimens be studied microscopically by competent petrographers, and that a sufficient number of representative specimens, properly selected, be analyzed by competent chemists.

For the purpose of a general reconnaissance it is not necessary, however much it be desirable, that the specimens be collected by a trained geologist or petrographer. Our knowledge is so fragmentary, and the gaps are so many, that even

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random specimens from the many as yet unknown islands, or even from the islands supposed to be well known, would be of great use and interest. Even pebbles from the beach would be better than nothing and would teach us something, in many cases. All of which serves to show how much is needed to give us a fair knowledge of the Pacific rocks.

At a meeting of the Section of Volcanology, of the American Geophysical Union, held in May, 1920, the suggestion was made that such collections, which would add much to our knowledge, might be made by the officers of vessels sailing in the Pacific. These would include official or semi-official vessels, such as Government warships or the "*Carnegie*," vessels belonging to various expeditions, such as the Dominick; or trading vessels, large or small, that visit the various islands. This suggestion was laid before a meeting of the Section of Volcanology at the Pan-Pacific Conference, and was discussed with approval.

As regards the *Carnegie*, the steamer of the Department of Terrestrial Magnetism, of the Carnegie Institution of Washington, it is a pleasure to say that the Director of the Department, Dr. L. A. Bauer, has expressed great interest in these suggestions, and that, following his instruction, Capt. Ault and other officers of the *Carnegie* have been kind enough, during the last cruise, to collect and send to me for study various rock specimens of considerable interest, collected at different little-visited stopping places. Some of these specimens will be studied in the near future. I am assured that, during future cruises, they will keep this matter in mind and collect such specimens as may be possible. I am sure that all students of the petrology of the Pacific will be at one with me in expressing the apreciation of geologists to Dr. Bauer and to the officers of the *Carnegie*, not only for the specimens that they may thus make available for study, but still more for the example that they set to others with like possibilities of rendering service to science.

At the meetings referred to, the suggestion was made that the aid and cooperation of intelligent inhabitants of the various, especially less well-known, islands might also be invoked. This would include government officials, merchants, or others resident on the islands. The great value of such intelligent cooperation is most strikingly shown in recent

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papers by Prof. Lacroix, some of which have been cited in previous pages. For much, if not the most part of the knowledge of the chemistry of the Pacific, he has been dependent on the collections made by such generous persons, who, at very considerable cost of time and effort to themselves, have collected such rocks as they could, and have thus enabled us, through them and through his studies of their material, to arrive at a much more detailed and better knowledge. Dr. Marshall has also had the advantage of such assistance, as may be seen from perusal of his papers cited above. I can only express the hope that these examples will be contagious, and that, not only will the French and British island residents continue their good work in unselfishly collecting material for study by petrologists, but that the residents of other nationalities, for example the Americans on the Pribiloff, Hawaiian, Guam, Philippine, and Samoan Islands, may emulate the most excellent example set before them. It it one that is capable of yielding results of very great value to science and to our knowledge of the Pacific, and one which will be appreciated by all students of the earth and its constitution.

All such efforts, valuable as they may, and undoubtedly will, be, however, should be superseded or supplemented, so far as may be possible, by more systematic efforts, and it is with the greatest pleasure that I endorse the suggestion of Prof. Daly, published in his two papers of 1916 cited above, for a thorough, systematic, and coordinated petrological and geological study of the Pacific volcanoes and their rocks.

As mentioned above, the collecting of specimens and the making of notes as to their occurrence is but a step preliminary to their proper study. The specimens collected should, or could, be sent in to certain centers, where they would be adequately studied, analyzed, and where the appropriate papers embodying the results would be published. A number of such centers suggest themselves; such as the various geological museums, surveys and universities of Australia, New Zealand, and Japan; the United States National Museum or the Geophysical Laboratory; and the Bishop Museum, which might act as a clearing house for the proper distribution of such material, as was suggested during the conference.

The important things to be borne in mind are:

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1. That specimens of the various Circum- and Intro-Pacific volcanoes should be collected as widely and as systematically as possible, and with appropriate notes; but, in any case, that they be collected;

2. That they be placed where they will be available for study by petrographers;

3. That they be studied petrographically and analyzed chemically by competent men, of whatever Pan-Pacific nationality;

4. That the results of such studies and analyses be published and thus made available to all students, not only of the Pacific, but of the earth.

We *must* know more, much more, of the chemistry and the petrography of the Pacific volcanoes; it is to the interest of every student of the constitution—chemical, physical and tectonic—of the Earth; and all the Pan-Pacific nations should cooperate in aiding and forwarding such studies. As for the petrologist, his position is Tantalean. Like Lazarus he is asking for a drop of water; while hoping for bread, he would welcome a stone.

DISCUSSION

MR. HOVEY: Attention is called to the obsidian flows of Iwojima, Japan, and of Mount Ararat, Armenia, and to the rhyolite of Mono Lake, California. It is believed that the explanation given by Professor Daly of the obsidian of Yellowstone Park, namely, that such a substance may represent the upper layer of a bathylith, is incorrect.

MR. JAGGAR: The iron content of the Hawaiian lavas is various, ranging from 11 per cent to almost 20 per cent in different specimens.

MR. WASHINGTON: The total amount of iron oxdies in various types of rock tends to vary with the specific gravity and the relative amounts of ferrous and ferric oxides with the degree of crystallinity. Recent analyses of Hawaiian lavas made by me show that of the earlier estimates of iron content those above 12 per cent are too high.

MR. DEAN: A copper salt in process of sublimation was observed on the edge of a red hot crack on the summit of a lava heap of Kilauea called Mauna Iki. Strong decay of the rock is going on at the margin of Halemaumau and soluble sulphate collects in the new tunnels recently vacated by hot lava.

MR. JAGGAR: Are the copper salts which have been occasionally found at isolated cracks in Halemaumau, on the floor of Kilauea crater, in Kau desert flow of Kilauea and at the low channel of the Alika flow of Mauna Loa near the sea in each case a product of a concentration process located at the place, or does the copper in streaks exist in the rock at that place? The most complete quantitative analyses of Hawaiian lava which we have make no mention of copper.

MR. WELLS: This does not necessarily indicate that the analysts had tested for copper.

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MR. JAGGAR: The occurrence of sulphate in the caverns of fresh flows at Kilauea appears to indicate a reaction between the sulphuric acid in the flow gases and the lava of the flow which was entirely cut off from the supply of fresh gas as the flow had become isolated from the pit after the lava sank in November, 1919. Apparently the sulphurous acid gas contained in the caverns was acted on by the ferric oxide of iron as a catalyser and converted to SO_3 which in turn acts on the rock constituents to produce the various metallic sulphates, there being a great quantity of water vapor present which condenses in the pores of the rock. Sulphate solutions drip into the cavernous spaces and the crystalline deposits are produced as the caverns cool. It thus appears that a considerable percentage of the original sulphur and metals contained in the hot lava may be removed in this soluble form, so that analysis of the cold rock is not identical with that of the hot magma.

MR. WASHINGTON: Some of the copper salts mentioned by Dr. Dean and Dr. Jaggar was collected after the conference adjourned. It proved to be apithitolite, a sulphate of sodium and potassium, colored by copper. (Communicated to the Publication Committee, July, 1921.)

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THE TECTONIC ASPECT OF VOLCANIC ERUPTION IN HAWAII

By H. O. Wood

(Preliminary statement expanded by the author from the stenographic record of the Proceedings.)

We all know that progress in science is made largely through the repeated examination of a body of facts, old and new, in new ways or from new points of view; or sometimes in the consideration of newly assembled facts from older points of view which may have been discarded, or in abeyance for a time. The information and trial of hypotheses is the way to clearer understandings of the complex fabric of nature. This is the sole justification, *at the present time,* for the discussion which follows, and for the brief and informal treatment adopted here. The subject is one which merits a much more thorough discussion than can be undertaken here.

What is said here of the volcanic process in Hawaii must be considered as hypothesis simply at the present time. More and more crucial work is required to demonstrate the success or failure of the hypothesis advanced. *This must be emphasized,* notwithstanding the fact that the view is one already received (and one applied far more widely than to the region here under discussion), among a circle of geologists much larger than the writer had suspected until recently. But it must be emphasized, too, that it is a view in accord with a large and growing group of facts, formerly not known to volcanology when the prevalent, or recently prevalent, views regarding volcanic action were formulated. It may be stated, too, that a strong argument in support of the view here advanced could be prepared. That, however, is not the present purpose. This is, to lay before you for consideration, without prejudice, a conception of the mechanism of volcanic action in Hawaii dependent chiefly on crust strain of tectonic origin and only in very subordinate degree upon the tension of volcanic gases, which is admitted to play a great part in eruption, or in certain stages of eruption, in many volcanoes.

The view that regional overstrain in the neighborhood crust sometimes might be the controlling causative factor in the extrusion of lava from vents in Hawaii was first suggested

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to the writer by his study of the 1868 earthquake here. This was a shock of great power. Just before it occurred the lava lakes in the crater of Kilauea were large and numerous, and activity in them was considerably greater than had been usual in the several years immediately preceding. An unusually good outlet for accumulated gas under great pressure thus existed, had any very excessive gas tension within the edifice of the volcano been in fact accumulated. (In making this statement the viscosity of the lava is not overlooked, for in any event this vent was fluid and large in area and weaker than any part of the solid shell of the mountain.) Also, the shock which brought relief was preceded for several days by hundreds of smaller shocks, some of which were caused by the opening of new fissures on the dome of Mauna Loa near its summit, where a "pillar of smoke" was seen to ascend. Thus new additional outlets were opened, but the escape of gas through these was of brief duration and no great volume of escaping fumes was seen. This was, in fact, noted by only one observer, though frequent shocks had awakened watchfulness in many. At the time of the culminating shock in the afternoon of April 2, 1868, several days after the crisis was first noticeably heralded and after the "pillar of smoke" had been seen, both Kilauea and Mauna Loa were split open forming a simple system of new fissures extending from the summit craters of both mountains southward to the sea; and, in addition, the southeast coast of Hawaii subsided differentially by amounts which varied up to a maximum of seven feet. The shock was felt sensibly throughout the Hawaiian group (except, perhaps, Niihau and Kauai), and was, practically without doubt, a great tectonic earthquake. Furthermore, the rift zones of Kilauea and Mauna Loa and the escarpments of the southeast coast and elsewhere, testify to the occurrence of many such earthquakes in the past. This indicates that great and widespread regional strains have been built up and relieved on many occasions here.

At the time of the culminating shock a lava flow broke out on the south flank of Kilauea. This was not observed closely, but it was, on land at any rate, of no unusual magnitude by comparison with other Hawaiian flows, as may be seen in the field today. It appears smaller than most flows. Also the amount of drainage from the crater of Kilauea

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which simultaneously occurred indicates a flow of less than normal volume only. Though the volcanic outbreak was not observed closely there were many who experienced the event who were living at no great distance whose attention would have been attracted by any outpouring of volcanic fumes on a grand scale. It may be asserted confidently that there was no such emanation (except the usual subordinate amount released from the surface of the flow) from the great fissures split open at the instant of the shock. At the same time Mauna Loa was rent open without any observed emanation of gas in conspicuous volume; and on this mountain lava did not emerge from the fissure until April 5th, when a flow, apparently less than normal in volume, burst out and made its way to the sea. This flow was observed closely by residents endangered, therefore under circumstances making for anxiety and not calculated to induce calm investigation, but no significant emission of fumes was noted. Indeed the whole event strongly suggested the following explanation: a local region, which happens to be volcanic and to include two great craters, had reached a condition of critical, elastic, crustal overstrain, a condition therefore which could not be relieved by the outwelling of lava from the craters. Consequently complicated faulting took place with the production of countless shocks in advance of and following the main shock. Fresh vents were opened and subordinate quantities of volcanic gases escaped relatively slowly (not explosively) from magma thus afforded contact with the atmosphere at places remote from the previously open vents. The magma beneath ground appears to be very viscous and occluded gases move through it very slowly but great gas tension should have forced outflow from all vents without rapid movement of the gas through the viscous melt. At the same time lava ran out or was squeezed out through the newly opened vents until the strains were relieved and readjusted to a supportable value. There is no suggestion that gas pressure, accumulated to an insupportable tension, was the cause of the action observed. Nothing of the explosive order occurred, and the circumstances of flowing, especially from Mauna Loa, do not even suggest magma tumescence as a significant cause. Moreover, the amount of lava which was extruded is of a low order of magnitude in comparison with the observed subsidence of the coast.

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Action is suggested as though a bottle of feebly carbonated water or syrup were slowly sheared until, at first, minute cracks were opened from which the excess gas sizzled out, and later, larger cracks, sufficient to relieve the strain, or to reduce it to a supportable value, which would permit and perhaps compel some of the liquid to run out. This is a small scale picture of the action visualized on this occasion.

Such an idea is not new, at least in its basic parts. But it suggested itself to the writer in connection with Hawaii independently of its growth elsewhere, because of the, to him, clear interpretation of the events of 1868 which it allows. Thus it led him to further examination of the facts of eruption in Hawaii, with such an idea of tectonic causation foremost in mind.

Consider, then, the following train of events. In September, October and November of 1914, local earthquakes were registered in slightly greater number than their average or normal occurrence up to the outbreak of eruption in the summit crater of Mauna Loa in November, after which they became normal in frequency of occurrence. None of these shocks was strong. The event in which they culminated was very feeble, considered from a tectonic point of view. The first phase of the eruption in Mokuaweoweo was the rapid outrush of fumes from its central part in very considerable, but not tremendous, volume. At the moment of outbreak a small swarm of feeble shocks was registered. The rapid emission of fumes grew to its maximum within three to five hours and afterward fell off greatly. After eight hours diminution became noticeable and after eighteen hours very conspicuous indeed so that the fuming had become merely incident to the outwelling of lava. Eruption in the crater, however, continued for about two months accompanied by waning, though variable, output of fumes in very subordinate amount. At no time after the first day was the fuming of the *outrushing* order.

The source of eruption was found to be a straight, narrow zone of fissures, about a mile in length, traversing the floor of the main crater in a NNE-SSW direction, along which at first twelve, later four, and still later only one, sheet-fountains (broad along the fissure and narrow across it) were active.

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On the twenty-first day of eruption only the single chief fountain remained in play and the fume output was practically negligible, less than the usual release at Kilauea. While, later on, the fuming underwent slight and variable increases in apparent fuming, which led the writer to infer an increase in activity at the summit, there never was any recrudescence of *outrushing*. That phase was all over in less than twenty-four hours. *Yet the outflow of lava onto the floor of the crater was definitely much greater after the twenty-first day of eruption than the amount extruded before that time, long after by far the greater part of the gas had been released and any potential due to gas tension had been correspondingly reduced. And under all the circumstances this interval seems too great to be ascribed to lag in response in the output of lava.*

This summit eruption may be thought of as the first event in an eruptive sequence which culminated in 1916 (or possibly later still). What, then, is the testimony of the subsequent events?

In the early morning of the 18th of May, 1916, again a very considerable but not tremendous outburst of fumes *rushed rapidly* upward from a new vent high up on the south flank of the mountain. On this occasion rapid and voluminous emission was confined to an interval of less than four hours. (There is also one report of a nocturnal outburst of still briefer duration a few hours earlier.) Some thirty very feeble earthquakes were registered during an interval of about twelve hours before, during and after the fuming phase, or phases. Other than this there was no recognizable seismic prelude. Some twenty-four hours then elapsed without further seismic or volcanic event. Then, without any recrudescence whatever in the action of fuming, earthquakes began to be registered at short intervals. *Most* of these were stronger than *any* of the thirty that accompanied the outbreak of fuming, though any accumulated gas tension had been afforded a large measure of relief, and a vent had been opened where further relief might be obtained. These shocks continued to occur in greater and greater number, and the stronger ones reached greater and greater intensity, for several days; this held true even after flow had broken out, which occurred about 36 hours later (about 60 hours after the fume outbreak) at a place in the rift zone about thirteen miles further down the

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mountain than the source of the outrush of fumes. None of these shocks was of destructive magnitude, though they resulted from the opening of a zone of fissures nearly four miles long in the basaltic rock of the mountain. But their locus was in a zone of rifting which shows literally countless scars of former fractures. It was therefore a weak place. Nevertheless, gradual failure and the production of a new rectilinear fault-fracture in it was the source of this shaking. When flow had broken out the fumes released at its origin and along its course, though considerable of course, were insignificant in volume by comparison with those emitted in the earlier outrush from the higher source, where little or no lava was extruded and where only a few feeble shocks occurred,—although the flow continued for more *days* than did the outrush of fumes *hours*. As the flow declined the earthquakes fell off in number but those which did occur continued to be stronger than those of the early group. One of the last of the series was stronger than any previous one.

The writer understands that a somewhat similar sequence of seismic and volcanic events accompanied the eruption of Mauna Loa in 1919, and that analogous behavior characterized the Mauna-iki outbreak of Kilauea also in 1919.

The eruption of Mauna Loa in 1887 presents a similar history so far as observations are on record; and that of 1907, too, is likewise similar in such details as are available. There is nothing on record in connection with other eruptions here which is inconsistent with these histories, but in many instances the parallels are not complete perhaps owing to the defectiveness of the earlier records.

In the cases cited, and especially in the 1914-16 sequence, a tectonic mechanism of eruption, like that suggested so strongly by the events of 1868, would explain satisfactorily all the facts observed in field and station.

The following instrumental findings are also consistent with this view. Since the establishment of a seismographic station at Kilauea quite a number of "swarms" of small local earthquakes (from scores to hundreds in the swarm) have been registered. Several of these are illustrated on diagrams already shown and discussed by Jaggar in other connections. The shocks in these swarms, as well as other shocks here, may be separated into two groups as Jaggar has indicated:

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those referable (on the basis of origin-distance) to sources on Mauna Loa, and those probably referable to origins about Kilauea. The swarms clearly referable to Mauna Loa have been due to the genesis of fresh fissures in the crater or on the flanks of that mountain, as shown above. But the swarms referable to Kilauea have, except in the recent instance of the outbreak of the Mauna-iki flow, not been proved definitely to be due to fissuring. However, they have conspicuously accompanied rapid subsidences in the pit crater of Kilauea. Halemaumau. Some of these subsidences have been very abrupt and their association with the shocks very clear. No *rapid* subsidences have occurred without the accompaniment of such shock swarms since seismographic instruments have been set up here. It is reasonable to infer that on these occasions the mountain has been fissured at moderate depths as a result of crust strain and that simultaneously magma has flowed into spaces thus opened, forming dikes or sills in the flanks of the mountain, thus quickly lowering the level of melt in the pit.

It is possible to offer other explanations of this action more in harmony with views in which gas tension is involved more prominently. But, whatever the future verdict of volcanology, these are not now more probable mechanisms than that here suggested. In this connection one thing now seems sure, that the shocks in question do not in general emanate from the axis of the pit crater (unless from very considerable depth), and so cannot be due to collapse there either of fluid or of solid masses, nor to explosive action in any ordinary sense. If the *sudden* withdrawals of lava in Halemaumau are in some way due to decrease in gas tension in the magma system, numerous shocks of moderately deep but not very deep origin from sources at greater or less distance from the axis of the pit must be explained *as to mechanism.*

This, then, is an hypothesis of volcanic eruption in Hawaii which deserves further consideration, and for some workers, more emphasis than it has hitherto received, and these are some of the facts and relationships which suggest and support it. It is not considered proved. Further work, critical observation, measurement and possibly experimentation, is required. The writer considers it a probable hypothesis, especially in the case of eruption in Hawaii. Both it, and all views

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which may be inconsistent with it, deserve the closest and most critical scrutiny. Should further work strengthen it and make it more probable than other views, the implications of many observations will be changed greatly. This is a matter of the greatest importance in volcanology.

DISCUSSION

MR. JAGGAR: Do you consider the substance underground which we call lava to be liquid?

MR. WOOD: I think the lava underground in the rift system was a liquid and so existed in the upper chamber of a batholith.

MR. WASHINGTON: Regarding the difficulty of transmission of the S waves of an earthquake through a liquid; such liquid might exist in reservoirs underground which would act merely as pockets within a rigid crust, the crust transmitting the wave motions around the pockets, and unaffected by them.

MR. WOOD: With properly disposed instruments of high grade it might be possible to map out the boundaries of a liquid body underground through the failure of the liquid portion to transmit the S waves.

MR. ROMBERG: In my opinion S waves might go through a liquid body and be converted into L waves in the process.

MR. OMORI: There are cases in Japan where the flood wave from a submarine earthquake started landslips which in themselves occasioned other disastrous waves. Was the 1868 disaster in Hawaii of that order?

MR. WOOD: I think not, as the whole Puna coast was faulted down, and in 1823 there was also a strong earthquake at the time of the eruptions in the Kau Desert.

MR. THURSTON: Dr. Brigham reported sunken stumps along the Puna coast in 1864. Ellis had reported a rift open near Kalapana, in Puna, in 1823. Asa Thurston reported active lava still visible near the top of Hualalai in 1823.

DR. OMORI: May I express the hope that precise bench marks might be placed across the Hawaiian volcanoes with a view to determining minute changes of level.

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FLOOR OF THE DEPTHS OF THE PACIFIC OCEAN, WITH REFERENCES TO VOLCANIC TOPOGRAPHY AND VOLCANIC OR SEISMIC DISTURBANCES

By G. W. Littlehales

In connection with a contribution for publication among the communications from the delegates to the First Pan-Pacific Scientific Conference, entitled "The Problem of Ascertaining the Configuration of the Basin of the Pacific Ocean," occasion has been taken to refer to the manuscript sheets of the bathymetrical chart prepared by the United States Hydrographic Office containing all the authentic deep-sea soundings, as evidence of the small extent to which the basin of the Pacific has been sounded and as showing the inadequacy of existing measurements to define the contours of configuration beyond the continental shoulder. Accompanying the mentioned communication is a chart of the basin of the Pacific, on a reduced scale, showing where the ocean has been sounded. In regions where soundings are represented in this chart, if all the recorded soundings could have been included there would, in general, be yet too few to admit of conclusions in relation to even the grosser aspects of the orography of the floor of the ocean. Nevertheless, there are some parts of the Pacific where the number and distribution of the measurements of depth have proved sufficient to afford an approach toward a fulfillment of this purpose, notably in the lane extending from California to the Hawaiian islands, of which a contoured map and profiles are published in United States Senate Executive Document Number 153, 52nd Congress, First Session, being the "Report of the Results of the Survey for the Purpose of Determining the Practicability of Laying a Telegraphic Cable between the United States and the Hawaiian Islands." Although, as yet there is little ground upon which to base general conclusions, the diversification found to characterize those areas about which most has been learned appears to support the view that the floor of the Pacific is extensively featured with orographical formations culminating at every stage of depth below the surface as well as above the surface of the ocean.

The published Hydrographic Office charts of the Pacific, especially those of the series of ocean charts whose designa-

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tions in the official catalogues are numbered 526, 527, 528, 529, 823, 823A, 824, 824A, 825, 825A, 826 and 826A, will be found to afford indication of these deeper banks as well as the Polynesian features and the banks of lesser depth, and to give indication, in connection with the soundings, of the nature of the materials covering the floor of the ocean, which are often composed of lava and other substances of volcanic origin. The books of sailing directions, called pilots, issued by the Hydrographic Office to accompany the nautical charts, are also to be recommended for the records they contain of evidences of volcanic and seismic disturbances, and this is yet further true of the monthly Pilot Chart of the north Pacific Ocean and the quarter-yearly Pilot Chart of the south Pacific Ocean particularly as concerns reports of seismic shocks at sea and great sea waves.

DISCUSSION

MR. OMORI: The submarine cable companies should be induced to furnish the scientific authorities of their governments with complete profiles and other data such as cause of breaks in cables. The cable broken at the time of the Sakurajima eruption was ruptured by tension.

MR. WASHINGTON: It is very desirable that accounts of submarine earthquakes and eruptions should be gathered from the logs of ships, and that mariners should be urged to make full records

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A PROGRAM FOR THE STUDY OF THE VOLCANOES OF THE ALEUTIAN REGION

By Robert F. Griggs, Director of the Katmai Expeditions of the National Geographic Society

(Presented by invitation of the Committee on Program.)

No group of volcanoes is more active or interesting than the Alaskan chain which stretches from the head of Cook inlet, some 1200 miles, to the tip of the Aleutian islands, and none is less known. More than 50 peaks in this chain have been definitely reported active within historic times. But knowledge of the country is so meager that it is quite certain that a geological examination would greatly increase the number of vents from which eruptions may be expected at any time.

One does not have far to seek for verification of this statement. Before the great eruption of 1912, only two of the five volcanoes of the Katmai district were recorded as such. And these two were mere names on the map concerning which no real information was available. Nothing can be more certain than that important eruptions will occur from one or another of the almost unknown volcanoes of this chain every few years.

But the distances are so great and the transportation facilities so meager that the volcanologist has little chance of learning of an eruption until long after it is over. An interesting case in point was the visit of Prof. T. A. Jaggar, Jr., to Bogoslof in the spring of 1907. The trip was undertaken merely because Bogoslof is a unique example of a submarine volcano which Dr. Jaggar wished to study. But when he arrived he found that an eruption had occurred only a few months before, so that he had reached the scene at a most opportune time.

It more often happens that the seat of an important eruption is not studied for years afterward, as in the case of Katmai whose crater was not examined until four years after its great eruption. It is impossible to estimate how much greater and more illuminating would be our knowledge of this eruption if someone thoroughly familiar with the ground beforehand and equipped to make the necessary observations on temperatures and a collection of gases given off, had studied the eruption immediately. Today we know only that during and immediately following the explosive phase of the eruption there were numerous activities of very great magnitude concerning whose nature we have only inference where we might have had precise infor-

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mation. Looking backward we cannot question but that the value of such information from a practical, as well as a theoretical point of view, would exceed the cost of maintaining a staff of trained observers in the region for many years.

There still remains much work to be done on the manifold aspects of the eruption of Katmai. But the most pressing need of science in the Aleutian region is exploration of the many unknown volcanoes and the maintenance of a corps of trained observers prepared to investigate every new eruption. Such exploration would build up a secure basis of data concerning the volcanology and geology of the region that would be of inestimable service in the interpretation of future eruptions.

Comparative observations along the whole length of the volcanic axis would enable us to gain some conception of the past and present manifestations of volcanic forces along the chain taken as a unit. For it is highly probable that in many of its aspects the whole chain presents a single problem. There can be little doubt but that the volcanoes of this district are all outlets of a single fundamental fracture in the earth's crust, despite the fact that it crosses the most diverse sorts of geological structure. Comprehensive correlations which would permit an historical conception of the activity of this great chain could hardly fail to throw light on the great problem of the relation of volcanic activities to the deformation of the earth's crust.

During the course of such exploration one or more important eruptions would be almost certain to occur. In such an event a well-equipped party would be on the ground prepared to study the outbreak with very good prospects of making important contributions to our understanding of volcanoes. In such work it is essential to be able to move promptly to any point at which activity develops. Inasmuch as every one of the volcanoes of this district lies within twenty-five miles of the seaboard, it is entirely feasible to equip a laboratory able to carry on a large variety of work and yet capable of being moved to any location demanded by the work in hand. The first and most imperative need for the development of volcanology in the Aleutian region is, then, a floating laboratory capable of serving as a base for the exploration of the peninsulas and adjacent islands.

What is needed is a vessel large enough to provide the required living and laboratory quarters, staunch enough to endure the bad weather for which the region is notorious, and

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with speed enough to utilize favorable opportunities for making dangerous landings, etc. There is work enough in this district to occupy such a vessel fully for several decades. If she were manned with competent investigators, there can be no doubt but that she would make a very great and important contribution to our knowledge of volcanism and its bearing on human affairs.

The usual method of procedure when no exceptional activity was in progress would be to begin work in the spring about as soon as the days became long enough to permit a party to operate to advantage, utilizing the snow for sledging provisions inland to the sites of the permanent camps to be used during the ensuing open season. The parties would then work in the field as long as weather permitted (October or November), and return to the states during the winter months for that fresh contact with other scientific workers which is so essential to continued productivity. Such a plan of procedure using a comfortable vessel as a base would not only greatly reduce the labor of getting supplies into position which is at present the bugbear of every party working in the country; it would also greatly increase the amount of work that could be done by a party in a season, for no time would have to be wasted handling supplies during the short season most favorable for work.

The cost of such a project may at first sight appear prohibitive. It is necessarily much greater than a study of volcanoes located in civilized regions. But from the nature of the case this project can not be compared with an ordinary geological survey. It is more nearly comparable to Arctic exploration. Judged by such standards, it is relatively inexpensive, for not only would the first cost be much less, since a smaller vessel would suffice, but the total cost distributed over a period of years would be very much less because the work would occupy such a vessel continuously for many years. Further, the scientific results to be obtained are in all probability of far more importance and value than the results of Polar explorations.

It is certain, moreover, that this region can never become adequately known until such a project is undertaken.

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SUGGESTIONS FOR THE STUDY OF VOLCANOES

(Report by Henry S. Washington on a Meeting of the Section of Volcanology of the American Geophysical Union on Methods of Volcano Study.)

The meeting was held May 26, 1920, Messrs. Bauer, Bowie, Cross, Day, Sosman, Washington, and Wood being present. The object of the meeting was to discuss some possible suggestions regarding the study of volcanoes which Dr. Washington might present to the Pan-Pacific Scientific Conference to be held at Honolulu later in the summer.

It was suggested, after discussion, that no specific recommendations be made, but that some of the more desirable subjects of possible importance that might be brought before the attention of the Pan-Pacific Conference were:

1. The importance of the collection of data on volcanic eruptions and the making of a catalog of volcanoes;

2. The enlistment of the aid of mariners, commanders of vessels navigating the Pacific, and of inhabitants in the various islands, in collecting such information; and also specimens of lavas;

3. The importance of the study of log books of vessels navigating the Pacific, which contain many data and observations now lost to science, and which would be of much value in the study of the volcanoes of the region.

After expression of interest in the aims and work of the Pan-Pacific Conference, and the desire to be of assistance in such ways as might be possible, the meeting adjourned.

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THE BEARING OF VOLCANIC OBSERVATORY WORK ON SELENOGRAPHY

By William H. Pickering, Assistant Professor of Astronomy, Harvard Observatory

(Presented by invitation of the Committee on Program.)

It appears to the writer that the most useful work that can be done in Selenography at such an observatory, by those who are not professional selenographers, is in obtaining and publishing photographs, such as illustrate the Monthly Bulletin of the Hawaiian Volcano Observatory. I have particularly in mind Volume 8, No. 9, recently issued. The terraced walls, and the small crater lake there shown are distinctly lunar in appearance. Photographs showing the elevation of the rim of the lake above the central plain when the lava has partially withdrawn and above the surrounding surface would also be valuable.

Should a central peak at any time be produced, such as occasionally occurs in the case of the more acid lavas of Europe and the Azores, this would be of decided interest. Craterlets scattered irregularly over the interior of a larger crater, on the other hand, are common, both on the moon and in Hawaii. I have in mind Haleakala and Kilauea Iki. Lines of minute regular craterlets lying along a volcanic crack, especially if they were confluent, or nearly so, such as we find in the crater rills of the moon would be particularly valuable.

All of the more striking volcanic features of the lunar surface have now been fully explained by terrestrial analogies and examples. The photographs above suggested would therefore be largely for educational purposes, among those geologists, and that portion of the public not familiar with the lunar surface, rather than for original lunar research. But at the same time there may be minute details of the lunar surface, visible under favorable circumstances, which would strike the eye of a trained volcanologist, and which would not be noticed by one not so trained. In such a case these photographs might be of the greatest assistance.

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REMARKS ON VOLCANOES

By Henry S. Washington

(Delivered extemporaneously at the Kilauea session of the Conference at the request of the Committee on Program. Stenographic report revised by the author.)

Regarded as earth phenomena, that is, from the point of view of the earth as a whole, volcanoes are very small and almost insignificant affairs—one might say, only little pimples on the "face of the earth." On the other hand they are of very great importance from the human standpoint, both as an element of danger to the lives and property of those who are fortunate, or unfortunate, enough to live near them, and because beneficently the soils formed from their ejecta are among the most fertile that we have. Scientifically, also, they are of the very greatest interest, both in themselves as one of the manifestations of the natural forces of the earth, because they are connected in some ways with some ore deposits that are so useful to mankind, and because they are among the few means that we have of arriving at a knowledge of what sort of matter exists, and what physical and chemical conditions may obtain, beneath the surface of the earth, which we call its "crust."

We know very little about the interior of the earth, and much of what we know is derived from the study of volcanoes and earthquakes. But we are fairly sure of the following:

1. The interior is essentially—or, at least, behaves essentially like—a rigid solid. That is, it is not formed of a comparatively thin crust covering an interior made up of "fiery" molten rock, but is solid throughout, from the surface down to the center; though, to account for volcanoes, we must admit the possibility of local melting or the presence of comparatively small "reservoirs" of liquid rock "magma."

2. The interior is hot, but of an unknown temperature, and the temperature probably increases more or less regularly toward the center, but with gradients (temperature increases) that are unknown beyond very shallow depths of about a mile or so, and that are very different in different places.

3. The interior is of a density greater than that of the rocks of the surface, inasmuch as the density of the earth as a whole is about 5.55, while that of the crust is about 2.77. That is, the earth as a whole is about twice as heavy as the rocks that we

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know, and probably at or near the center the density may be 8 or 10 times that of water.

4. The earth as a whole acts in many respects like a huge magnet.

5. From study of the propagation of earthquake vibrations through long distances, we are led to believe that there is a change in the physical and probably chemical characters at about 0.5 of the radius in depth, that is about half way down toward the center. Certain kinds of earthquake vibrations are damped or stopped when the earthquake studied is so far away that the waves have to pass through this deeper portion of the interior.

6. It is generally believed, from consideration of the density of the earth and the composition of meteorites, that part of the interior is composed of metallic iron, or of an alloy of iron and nickel, similar to what constitutes the iron meteorites.

There are several kinds of volcanoes, the forms assumed by them being in great part dependent on the general composition of the lavas and other products ejected. Thus we may have the so-called "fissure eruptions," such as the basalt flows of the Deccan in India and the valleys of the Columbia and Snake Rivers in the northwest United States, where the basaltic lavas, which fuse at low temperatures and are very fluid, issued mostly from cracks or fissures, and poured out in vast floods of very liquid lava which flowed over the surrounding country like floods of water. At these eruptions there was little explosive action and consequently little formation of volcanic ash, so that true volcanic cones are few, subsidiary in importance, and very low and flat because of the fluidity of the lava.

There are the so-called strato-volcanoes, in the form of more or less regular cones, built up of irregularly alternating beds of ash or lava flows, according as the various eruptions were more or less explosive in character. The lavas of which these are composed may be quite various, ranging from those very high in silica, called rhyolites, through those of medium silicity, called andesites, to low silica rocks, the basalts, such as are most of the rocks of the Hawaiian islands. The volcanoes of the great "circle of fire" that surround the Pacific, including the entire length of the Andes, with the offset of the West Indies, the extinct volcanoes of the Cordilleras in the United States and western Canada, the more or less active volcanoes of the Aleutian islands, and so around and down the western coast

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of the Pacific through Kamchatka, Japan, the Philippines, etc., to the Dutch West Indies, are generally of this type. The well-known volcanoes of Vesuvius and Etna are also strato-volcanoes.

There are also some volcanoes the lavas of which are very high in silica, and as such magmas are much less fusible than the basaltic ones, we find that the lavas issued at these, not as more or less liquid lava, but as a stream of half-solidified, angular, very glassy blocks, or else formed domes (not cones), of generally small size, but with steep sides. We see examples of these at Santorini in the Grecian Archipelago, the Island of Lipari, and on the Island of Pantelleria near Tunis.

Another type of volcano is that in which the eruptions have been almost wholly explosive, so that the "volcano" consists of what is really only "a hole in the ground," produced by the explosion of the gases (of which we shall speak presently), and with the emission of little lava or true ash. Such volcanoes are found in the volcanic region of the Eifel in the Moselle valley.

The volcanoes of the Pacific islands, including those of Hawaii, are very largely basaltic, and may be classed with the strato-volcanoes, though the lavas generally have been so fluid, and the formation and ejection of ashes so slight, as compared with the emission of the fluid lavas, that they may, perhaps, better be classed with the low and wide-spreading cones that may accompany the basaltic fissure eruptions. Kilauea, on which we are now, is an excellent example, and the angle of slope of its flanks is so slight that you will all have noticed that the ascent the other day along the forest-clad road was more like a drive along a plain than the ascent of a volcano. Mauna Loa, which rises up before us now, and Mauna Kea, to the northwest, also show slopes of only a very few degrees, due to the general liquidity of the basaltic lavas.

Besides the mineral constituents of lavas and other igneous rock, the magma—that is, the molten substance that comes up from down below and which solidifies as rock—contains very considerable quantities of gases. These are held in solution in the highly heated liquid, very much, or indeed quite the same, as carbonic acid gas is dissolved in a bottle of beer or of soda water, or as air is present dissolved in ordinary water. In the depths, far below the surface, the pressure is so great that these gases cannot escape, but as the columns of liquid lava approaches the surface, in the crater of the volcano, the pressure dimin-

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ishes, permitting the gases to escape, just as it does on opening a bottle of beer. Whether it escapes quietly and gradually, or more rapidly, and sometimes even with great explosive violence, depends upon the character of the lava, whether it is more or less liquid or viscous(this being largely dependent on its chemical character), on the amount and kinds of gas present, on the temperature, on the depth and size and shape of the orifice, and on other such factors. In the pit of Halemaumau we have an example of very quiet outpouring of gas, this being due, probably chiefly to the great liquidity of the basalt, partly because of its chemical composition (lavas that contain much iron oxide as do these being very fusible and liquid), and partly because of the size of the vent. Halemaumau and the reservoir of liquid lava below may thus be likened to that delectable product of a vanished and more sane and civilized age, before the enactment of the 18th Amendment, a bottle of beer or champagne, the pit, which we have looked at with such interest and admiration, being the neck with the cork withdrawn, and the reservoir below, of unknown dimensions, corresponding to the bottle.

The gases that are present in lavas or in the magma are very varied. The most abundant is water vapor, which is almost always present in by far the greatest amount, and which forms the bulk of the enormous clouds that arise from volcanoes in activity, often to the height of several miles. Among other gases present may be mentioned hydrogen, hydrochloric acid, sulphur vapor, sulphur dioxide and trioxide, and carbonic acid, with smaller quantities of others.

Kilauea, and especially the pit of Halemaumau, has a classic and prominent place in the annals of volcanology, because of the comparatively quiet emission of gas from the lava, and the ease of approach to the points of their emission, thus rendering the collection of the gases rather easy, as compared with many other volcanoes, though it is still a matter not to be undertaken too lightly. About 1911 Brun, a Swiss amateur student of volcanoes, propounded the theory that the clouds above active volcanoes, and the gases emitted from the lavas, did not consist largely of water, as was generally thought—indeed he denied the presence in them of water derived from the magma, holding that any water that might be present was due to infiltration or percolation from the surface. In spite of its manifest improbability and contradiction of the numerous observations of many life-long

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students of volcanoes all over the world, this hypothesis of an untrained man met, not with general dissent, but with a very favorable reception, possibly because of its essentially novel and improbable nature. The world in general, like the ancient Athenians, craves the novel and the startling. He held that the clouds consisted, in great part, of salts, especially of ammonia, soda, etc., or of sulphur trioxide and sulphur.

In 1912 Dr. Day, Director of the Geophysical Laboratory in Washington, became interested in the matter, and he and Dr. Shepherd, of the Laboratory, came out here to study the problem on the spot. After spending many months with Dr. Jaggar sitting on the edge of the pit, a favorable occasion presented itself, and Dr. Shepherd was able to collect in glass tubes samples of gas from the lavas uncontaminated, so far as was humanly possible, by air and which were thus practically unoxidized. (As you know, hydrogen, which is one of the gases in lavas, is oxidized to water, so that this possible source of water had to be eliminated.) Dr. Shepherd collected the gases in his tubes, brought them back to Washington for analysis, and found in the tubes very considerable quantities of condensed liquid water which, so far as it is possible to ensure in such a difficult bit of collecting work, was there as an original constituent of the magma, and could not be caused by oxidation of any hydrogen in the lava, or derived from rain water. Brun's theory was thus made doubtful, and these classic experiments, among the most important in the science of volcanology, have firmly established the formerly universally accepted fact that water *is* present in the magma, and is one of the most abundant constituents of volcanic clouds. There were also secondary pieces of evidence, into which we cannot enter here. The gases of Kilauea are now being collected by Dr. Jaggar from time to time, as opportunity presents itself, and are being analyzed by Dr. Shepherd, so that it is probable that this volcano on which we stand will for long keep up its reputation as, with Vesuvius and Etna, one of the most important and instructive volcanoes in the world.

I have laid stress on the gases in lavas, partly because they have been best studied at Kilauea, and partly because, largely through the studies of Day, Shepherd, and Ferguson at the Geophysical Laboratory, it is being recognized that it is highly probable that volcanic heat, and hence volcanic activity, is partly or very largely caused by the interreactions of the magmatic

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gases. We cannot go into this matter here, and I may only say that, as you know, nearly all chemical reactions produce heat, and, as the varied gases in lavas are capable of reacting among each other, combining and recombining according to the changes in pressure and temperature as the lava ascends the throat of the volcano the lava column is kept hot. This very interesting scientific question, one of great importance in the study of volcanoes, can be tested in some of its aspects by borings around and on the flanks of volcanoes, and, as you have probably heard, there is good reason to hope that, through the liberality and scientific spirit of a few individuals and organizations, it will probably be possible to begin such borings at Kilauea before long, so as to get some idea of the heat gradients and other conditions at an active volcano. The matter of the possibility of utilizing the heat energy of Kilauea can also be tested.

The next and concluding part of my brief talk I approach with diffidence, because it is a subject in regard to which we know little positively, and of which our so-called knowledge is largely guess-work. I refer to what lies beneath the volcano. Where do the lavas come from, from how far down, how did they originate, what makes them come up, what makes them hot? and other such subterranean matters which form the gist of the questions with which tourists endeavor to make our friend Jaggar's life a happy one.

Without entering into discussion of the dim and far distant past when the solar system and the earth itself were supposed to be nebulous masses gradually consolidating and developing heat, we are led to believe, as I have said before, that the interior of the earth is very hot: that is, probably so hot that the rocks would be melted if they were at such temperatures on the surface, especially as they contain gases, which lower their fusion points. On the other hand we know that the earth is solid, or practically so, throughout—certainly toward the surface, and we have reasons for thinking that volcanoes do not originate at great depths—that is, that their foci lie at depths of about, say, from 20 to 50 miles or so. In other words, they are merely surface or near-surface phenomena, as I have said.

The earth, being not a huge globe of "liquid fire" covered by a thin solid crust, but solid as a whole, we may postulate as an origin of volcanic lavas one of two alternatives. The lavas either originate from comparatively small (though, humanly

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speaking, large) patches, or masses, the so-called "reservoirs," of residual liquid matter left over in the mass of the earth, but not very far from the surface, and of such small size relative to the earth, and so scattered, that they do not affect appreciably the propagation of earthquake waves; or they come into being because the interior rocks, although hot enough to melt if they were at the surface, are under such pressure that they are kept solid, but melt on relief of pressure. We know from experiment that the minerals of which rocks are composed act in this way, and this supposition as to the origin of volcanoes harmonizes with the observation that many, if not most, volcanoes are found arranged along lines, which are lines of weakness or fracture in the earth's crust, thus giving relief of pressure and permitting the hot rocks to melt. The Hawaiian islands are an example of this; the volcanoes start from Kauai on the northwest, or from even beyond this, and run southeasterly to the extreme island of Hawaii, on which are the only volcanoes of the group that are active at the present day. The volcanic activity seems to have died out gradually along this line, in the direction mentioned, and such progression and successive cessation of activity is found in other volcanic regions, as along the line of volcanoes parallel to the west coast of Italy, the end volcano, Vesuvius, being the only present active one. (Etna does not belong along this line.)

There is another interesting feature of the structure of the earth, to the knowledge of which volcanoes contribute much of our information, and which is of special interest here because the mode of formation of the Pacific basin is involved. It is known to students of rocks that the lavas, the portions of the magma below which have reached the surface, as well as the more deep-seated igneous rocks, such as granites, which solidified at more or less great depth, vary very much in chemical and mineral composition. Without going into details, I may say that it has recently been found that the densities of rocks may be calculated from their chemical compositions, and by studying very many chemical analyses of igneous rocks from all over the globe, we are able to calculate the average densities of the continents, of the floors of the ocean basins, and of many of the countries, or rather of the masses of rock that compose them. When we correlate these average continental and other densities with the average elevations above sea level, the remarkable

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result shows clearly that the highest masses of the earth are made up on the whole of the lightest rocks, while the deepest parts are underlaid by the heaviest rocks. There is a definite and direct relation between the densities and the elevations. Thus, the average density of the rocks of the crust is 2.77 and the average elevation of the whole earth's surface is about 2200 feet above sea level. Asia, the highest continental mass, has an average elevation of about 3200 feet, and the rocks that compose it have an average density of 2.72; the corresponding figures for the United States are 2500 feet and 2.75, for Europe 940 feet and 2.75, for Australia 800 feet and 2.79. We can get our only idea of the materials that compose the oceanic floors by studying the lavas that have been or are being poured out by the volcanoes on oceanic islands, such as those of the Hawaiian islands. We find that, as a whole, they are very heavy, much heavier than those of continental volcanoes and igneous rock masses. Thus the Atlantic floor has an average depth of 12,800 feet below sea level and the average density of its rocks is about 3.05, while the Pacific has an average depth of 15,400 and its rocks have an average density of about 3.10. This is a broad topic into the discussion of which we cannot enter here, but it has a direct bearing on the so-called theory of isostasy, that the portions of the earth's crust are in a balanced condition, the lighter parts tending to rise and the heavier to sink; in other words the high continental masses are not kept up by the principle of the arch, but by that of flotation. Dr. Bowie has done very much to advance this theory.

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PAPERS ON SEISMOLOGY

EARTHQUAKE ZONES OF THE PACIFIC

By Fusakichi Omori

INTRODUCTION

An earthquake is caused when the stress in a given portion of the earth's crust reaches a limit and gives rise to the production of a sudden underground dislocation, crack, compression, elevation, depression, etc.; a large seismic disturbance being equivalent to the removal of an extensive unstable geophysical condition. Naturally there are non-seismic and seismic areas, and broadly speaking, the regions about the Arctic, namely, the northern parts of Russia, Siberia, and Canada, are subject to least seismic visitations, while the margin of the Pacific ocean forms the most active earthquake zone of the earth.

PACIFIC COAST

In South America there stands the great mountain range of the Andes right along the Pacific coast, while the sea off the latter reaches the depth of over 7,000 metres. The steepness of the surface gradient, which must favor the occurrence of earthquakes, exists also along the Pacific coasts of North America, the Aleutian islands, and of the Japanese islands. The two latter series of islands furnish, together with Sumatra-Java and the Himalayas, great well-defined peripheral arcs, with concavity turned toward the continent of Asia, the steeper or deeper region being always on the convex side. The arcual form in question may be supposed to be the result of a horizontal pressure applied from the inner, or concave, side. The genesis of this marginal action may be attributable to the possible sinking down of the great continental mass, which perhaps has already passed the limit of elevation and has entered upon the stage of settlement. Thus, in the arcs under consideration, the concave and the convex sides are to be regarded as areas of compression and of tension respectively. The convex, or tension, side forms in each case the principal seismic region; while the concave, or compression, side is essentially the volcanic region. This fact is well indicated in the Aleutian, Japan, and Sumatra-Java arcs, which abound in volcanoes and which are frequently shaken by great submarine earthquakes originating

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off the convex side. The distribution of volcanoes and seismic centers in Italy furnishes another example of the illustration of the same principle.
frequently shaken by great submarine earthquakes originating

VOLCANIC AND SEISMIC DISTRICTS

The Japan and other arc systems as well as the whole border of the Pacific may be regarded each as forming a volcanic chain or an earthquake district. Hence it is natural that in an epoch of activity great volcanic or seismic disturbances should happen in succession from different parts of such an arc as the result of the accumulation of the underground stress affecting the whole system. Thus, in Japan the volcanoes of Oshima, Sakura-jima, and Asama made tremendous outbursts in the years 1777, 1779 and 1783 respectively. After about 130 years, the same three volcanoes made again great convulsions between the years 1909 and 1914, although Sakura-jima is in Kyushu and widely separated from the two other mountains belonging to the Fuji volcanic zone. Between these two remarkable periods of the volcanic activity the epoch of 1853-1859 was one of an extraordinary seismic activity, there being no less than twelve destructive earthquakes in different parts of Japan; amongst others, the two great shocks off the southern and southwestern coasts of Japan on Dec. 23 and 24, 1854, produced *tsunami* or tidal waves, which crossed the Pacific and were recorded on the tide gauges at San Francisco, San Diego and Astoria.

PACIFIC EARTHQUAKE ZONE

Great destructive earthquakes do not take place in any district at random, but originate along certain weak lines in the earth's crust which may be termed earthquake zones. From figure 1, which indicates the distribution of the origins of the more prominent among the extensive non-volcanic earthquakes since 1897, it will be observed that the flat suboceanic regions of the north and southeast Pacific are seismically very quiet, while the most active earthquake zone runs off or along the coasts of South and North America and of the Aleutian and Japan arcs. In the southwestern part of the Pacific, several remarkable deep local basins are found off the arc formed by the islands of New Guinea, New Caledonia, and New Zealand, it being exactly there that great earthquakes originate. Taking the latter arc as denoting the real southwest boundary of the great ocean, we

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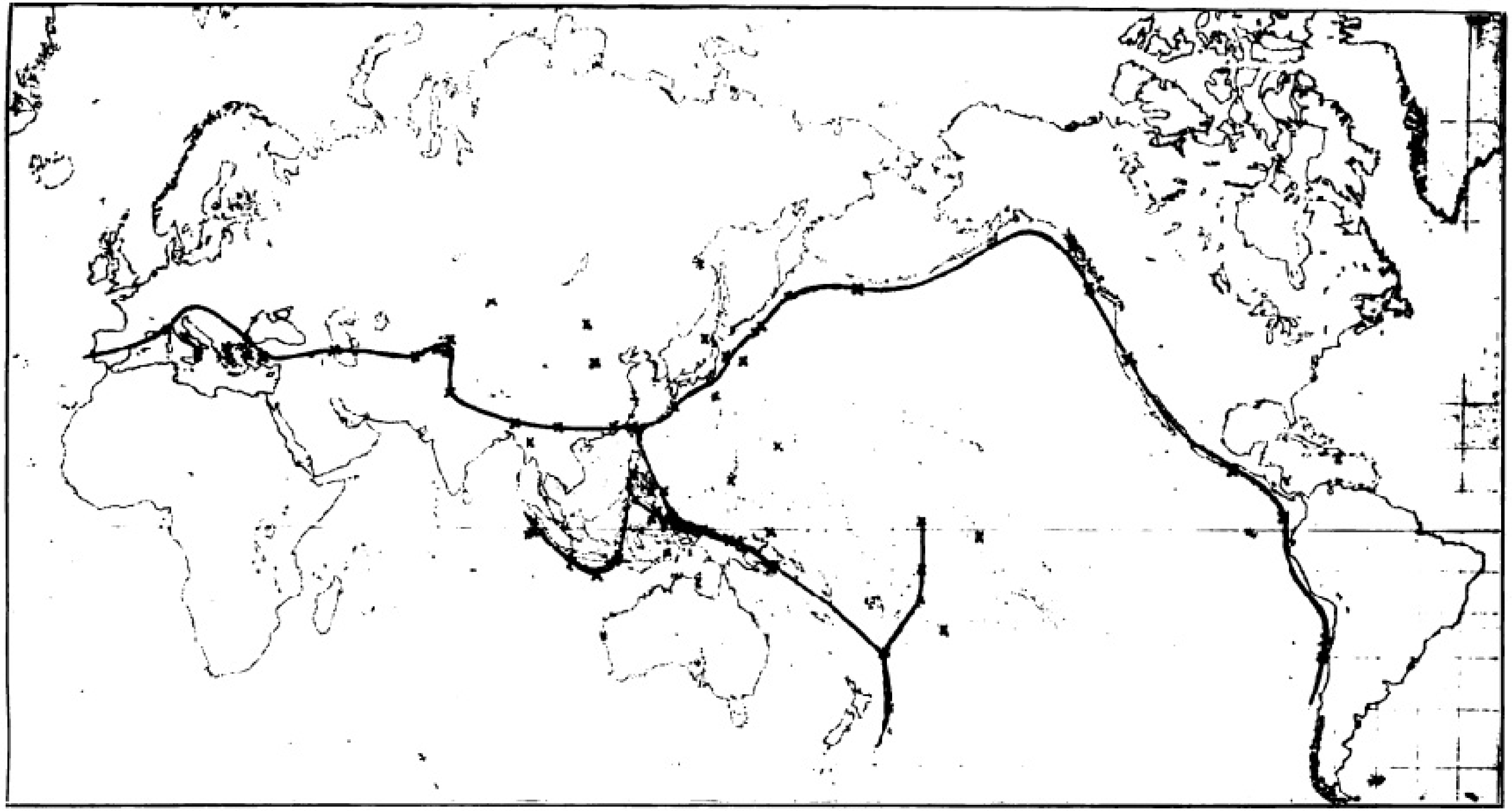


FIGURE I. Map showing the position of the Pacific earthquake zone and its Himalaya-Mediterranean continuation. The small crosses (x) indicate the positions of origins of the prominent large earthquakes in recent years.

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may say that the margin of the Pacific forms the greatest earthquake zone in the world. To the west it is prolonged to the outer base of the Himalayas, and, through Turkestan and Caucasus, to the northern coast of the Mediterranean. Large Pacific earthquakes are often accompanied by destructive *tsunami*.

EARTHQUAKE OCCURRENCE

Great earthquakes, which remove an over-strained condition in the earth's crust and which originate near the surface, occur at different parts of a seismic zone at different times, not repeating from one and the same point. Thus, the Japan earthquake on Dec. 23, 1854, took place off the coast of Tokaido, while the equally extensive shock on the next day originated from the same earthquake zone, but 200 miles to the west, off the coast of Nankaido. Again, the series of the great earthquakes: (1) off the southwest coast of Alaska in 1899; (2) the Mexico and Central America earthquakes in 1900 and 1902; and (3) the Panama, Colombia and Equador earthquake on Jan. 1, 1906; had to be regarded, not as independent unconnected events, but as the results of the stress accumulation at different parts of the seismic zone along the Pacific coast of North and South America. Thus the turn was to come next to some place between (1) on the north and (2) and (3) on the south, somewhere along the coast of the United States. This expectation was fulfilled in the San Francisco disaster on April 18, 1906. My further prediction that the next great shock would probably occur at the southern prolongation of the active part of the zone in question, to the south of the equator, was verified in the Valparaiso earthquake on Aug. 16, 1906. It is remarkable that this had been preceded by only half an hour by another great submarine disturbance to the south of the Aleutian arc. The almost simultaneous occurrences of two great shocks from the two extremities of the American branch of the Pacific seismic zone, at a mutual distance of some 10,000 miles, prove the existence of the zone itself. There are other cases in which great seismic disturbances occurred within a few years from opposite extremities of an earthquake zone. Thus, the 1897 Assam-Bengal and the 1905 Kangra (Punjab) earthquakes occurred nearly 1,000 miles apart at the external base of the Himalayan arc respectively near the eastern and the western ends. Again, the Messina earthquake of 1908 and the Avezzano earthquake of 1915 originated about 400 miles apart respect-

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ively near the south and the north ends of the central and south Italy earthquake zone. The occurrence of the Swatow earthquake on Feb. 13, 1918, is interesting, as the Himalaya-Mediterranean seismic zone had been assumed to be continuous with the America-Japan zone through the southern maritime provinces of Ohina, although these had no record of previous destructive shocks.

EARTHQUAKE PREDICTION

Studies on the time and space distribution of earthquakes and volcanic eruptions have thrown some light on the problem of the prediction of these events. Especially considerations respecting seismic zones give us in some favorable cases hints as to the probable locality of occurrence of future great tectonic earthquakes. The popular idea of repetition of destructive shocks successively at one and the same point is a great fallacy; a place seismically most dangerous being such as belongs to a powerful seismic zone, which has not yet, at least in historical times, been shaken by a destructive earthquake originating right under it or very close to it. An important task for the practical seismologist in an earthquake country is to make a thorough study of the location and history of the seismic zones, to infer the intensity of motion in future earthquakes likely to affect a given district, and suggest proper methods to be followed in architectural and civil engineering structures. The mitigation of the destructive consequences of earthquakes can be very materially effected by the adoption of even a slight amount of earthquake-proof measures. In Japan it is no rare thing for some peasants' cottages to remain standing even in the epicentral districts of tremendous earthquakes, as was the case in the Neo-Valley during the Mino-Owari earthquake of 1891.

RELATION BETWEEN EARTHQUAKE AND VOLCANO

Volcanoes and the centers of large tectonic earthquakes show distinct space distributions. (See figs. 2 and 3.) A volcano, whether active, dormant, or dead, may often become the center of numerous volcanic earthquakes. These are generally local and weak, and, even when strongest, belong to the category of what may be termed a small destructive shock, namely, one causing such damage as the fracture of brick chimneys, collapse of stone houses, loosening and breaking of cast iron waterwork pipes, etc. A volcanic district may be assumed to be free

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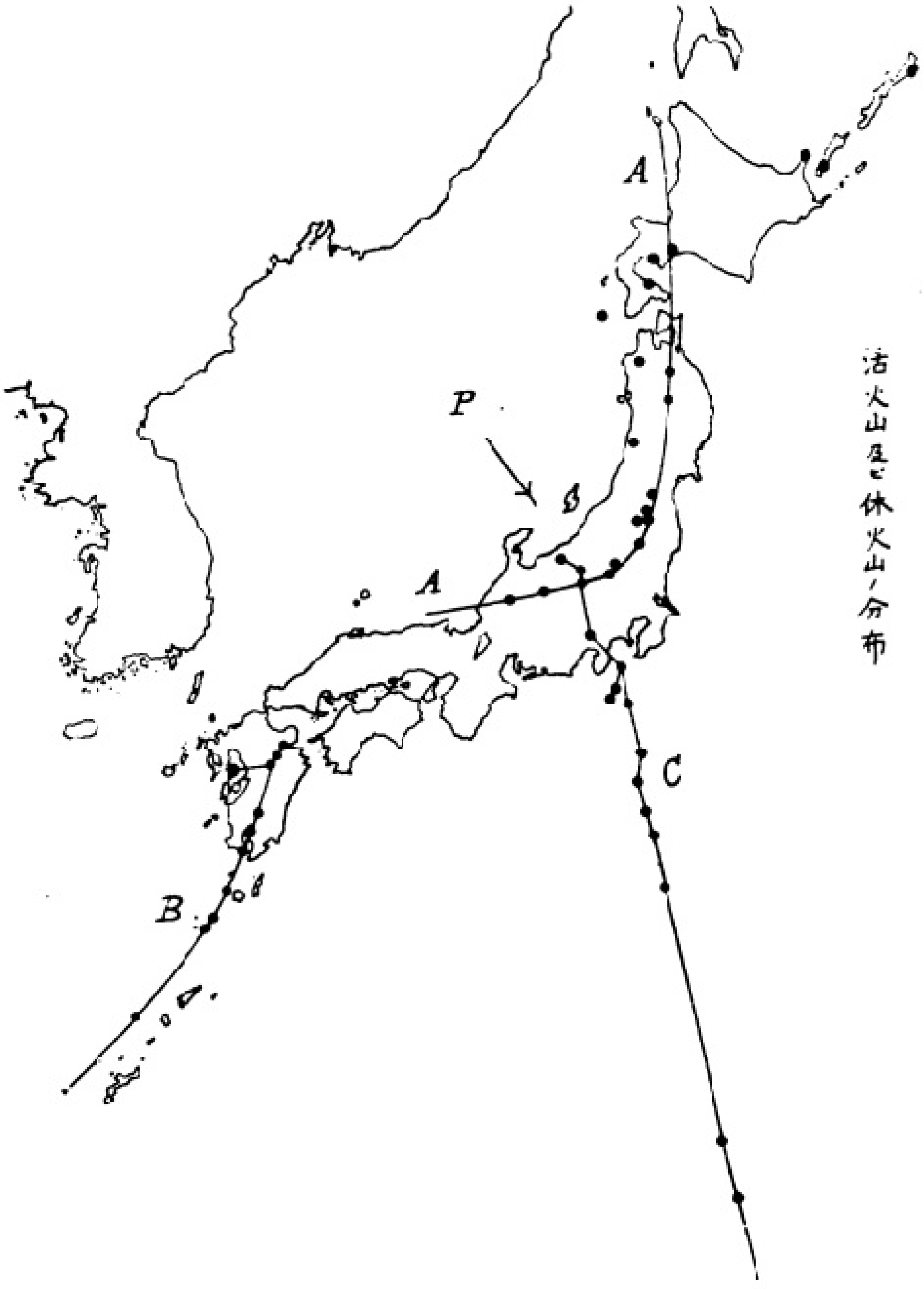


FIGURE 2. Map of Japan showing the distribution of the active and dormant volcanoes indicated by black dots. AA. Concave (compression) side volcanic district; C. Fuji volcanic zone; B. Kyushu and Lyukyu volcanic zone; P. horizontal force which produced the actual form of Japanese islands.

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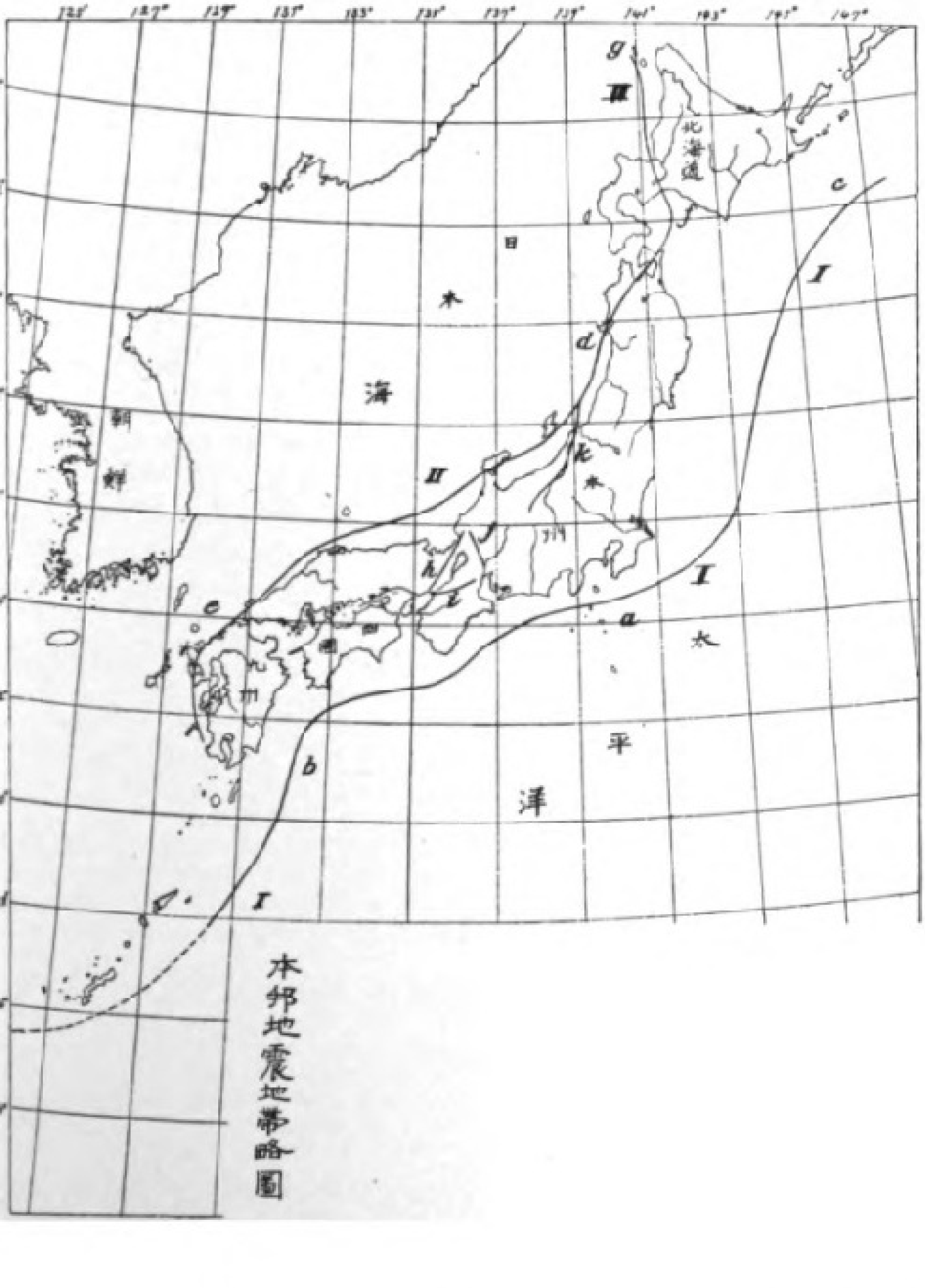


FIGURE 3. Map of Japan showing the principal earthquake zones. I, I. The principal or convex side earthquake zone; II, II. weaker and concave side earthquake zone; h, i, j. earthquake zones in central Japan; k. Shinanogawa Valley earthquake zone.

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from the visitation of a great destructive earthquake, namely, one whose area is extensive and whose intensity of motion is sufficient to destroy properly constructed wooden or iron buildings. Houses built of very bad building materials, whose tensile strength is practically zero, have no earthquake-proof capacity, and will be wholly crushed down or scattered about at once simultaneously with the commencement of the strong motion portion of the earthquake. These may, of course, be destroyed even by volcanic earthquakes of the severer intensity.

HAWAIIAN ISLANDS

The Hawaiian islands are not likely to be visited by such great seismic convulsions as take place along the margin of the Pacific. The stronger local shocks will, however, prove destructive to badly built structures of stone or brick. Consequently it is absolutely necessary that houses in the Hawaiian islands should be built with certain proper earthquake-proof precautions.

DISCUSSION

MR. ANDREWS: May the destructive effect of local earthquakes and large ones be clearly distinguished?

MR. OMORI: Destructive shocks of small local nature whose intensity of motion is not so high as in non-local earthquakes of large magnitude may be repeated from neighboring points. In Jamaica, the earthquake was local and small in magnitude. A very strong earthquake always is followed by a great many smaller or secondary ones, which are called after-shocks. Of materials for construction stone is not good, brick is better, brick with steel frames (like some "sky-scrapers" in the eastern United States) is still better, and steel concrete is the best of all. In Japan a great many wooden houses, even at the center of earthquake disurbances, will stand.

MR. SMITH: On one occasion in the Philippine islands three volcanoes were active at the same time. The best building material for a native house in the Philippines is bamboo tied together with rattan. A good kind of stone is used in Manila that cuts like cheese and hardens in the air. An egg-shaped house that will move on its foundation has been suggested. A reference book on the subject of earthquakes mentions Oregon as "a seismic hiatus." This is wholly inaccurate.

MR. BOWIE: We want elementary textbooks written by the great men of science. Professor Omori should write an elementary textbook on seismology for schools.

MR. WASHINGTON: In 1914, at Messina I found the town being rebuilt of light reinforced concrete along the lines suggested by Professor Omori. An Italian engineer and I examined two villages on the south slope of Aetna damaged by an earthquake in May, 1914. We found that destruction was due chiefly to two faults of construction: the house walls were badly built of rough rubble stone and poor mortar; but the chief fault was that the heavy timbers of the upper floor and the roof were let into the walls only about an inch, so they pulled out easily;

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also the roofs are covered by heavy tiles. Loss of life and destruction of buildings in Italian earthquakes is mostly caused by such faulty construction.

MR. JAGGAR: There is an experimental attempt by legislation to create a building law that will meet the emergency. Arthur Herschel, government engineer, carried out the earthquake law of 1907 in Jamaica. The City of Kingston is rebuilt of ferro-concrete. In regard to volcanic earthquakes, they are not commonly very severe, but may not great tectonic earthquakes be in some sense magmatic? The tectonic lines follow the American Pacific coast and thence to Asia around the sea. In the ocean the greatest deeps are along similar lines and we know very little about them. Out in the ocean south of Kilauea, Mr. Wood says, occurred the great earthquake of 1868. We do not know whether there is a line of active volcanoes along the great deeps, and volcanoes in the deeps would probably produce little sensible effect. I am strongly inclined to the view that the drop from high level in Halemaumau in 1911 was due to drainage probably out to sea at the south. Occasionally pumice is found floating around in the sea. People have seen sea water near Hawaii boil and pumice floating. The Alika flow made a few tidal waves. What was happening under the sea? Usually there is no clue. So there may be a close relationship between flexures and deep magmatic openings on Hawaii probably underground.

MR. J. S. EMERSON: Did the old pumice on Hawaii probably come from submarine volcanoes?

MR. JAGGAR: A great deal of the pumice on the surface in Hawaii is found around the base of ash sections, probably ejected from cones similar to those recently active on Mauna Loa. Pumice from the sea is from similar eruptions under the ocean.

MR. WASHINGTON: If such pumice from submarine eruptions be collected and studied, it might yield valuable information.

MR. VAUGHAN: On Dr. Omori's maps which show the earthquake zones around the Pacific, should not the line be drawn through Cuba and through northern South America to make an analogy with the earthquake regions in the same latitudes on the west of the Pacific. Here we have tectonic features. The earthquakes are obviously associated with great fault lines. The greatest deep is 30 to 40 miles north of Porto Rico. South of the south shore of Cuba the depth is 3,000 fathoms. Near Santa Cruz the depth is very great. So there is close association of tectonic elevations with oceanic deeps. The same relationship is shown also in Tonga.

MR. LITTLEHALES: Evidence of volcanic activity exist in the region of the Tongan islands near which the ocean floor is 5,155 fathoms deep. Volcanic cones have given evidence of their growth in regions where depths are great. Smoke and gases have been found by passing navigators to issue from the surface of the sea at points where years afterwards there might be an emergence of the volcanic mass. In the South Sea islands, much volcanic activity has been noted, and, no doubt, there are other regions where submarine volcanic activity has taken place.

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"REGIONAL" VERSUS "WORLD" SEISMOLOGY IN RELATION TO THE PACIFIC BASIN

By H. O. Wood

(Stenographic report revised and expanded by the author.)

INTRODUCTION

The purpose of this Conference is to consider ways and means for the advancement of science especially in matters affecting the basin of the Pacific Ocean broadly interpreted.

In such a program of research, seismology should have a great part to play. For, as is well known, nearly all the belt of lands which form the margin of the Pacific exhibit pronounced seismic and volcanic activity. Indeed, its nickname, "the fire girdle of the Pacific," visualizes this border zone vividly. Besides its volcanic activity, innumerable earthquakes, great and small, have originated in this marginal belt of sea-coast and islands, mountains and troughs. Also numerous tracts of seismic activity are located inside the basin of the Pacific, as in Fiji, Samoa, and Hawaii.

Here, then, is a most fertile field for seismologic investigation. What are the chief problems which beckon, and what needs most to be done?

THE BROAD DIVISION OF SEISMOLOGY

Two chief aspects of seismological science need to be clearly distinguished: on the one hand, the instrumental and physical study of great earthquakes in relation to the earth as a whole, *hologeoidal* (geoidal) or "world" seismology; and, on the other, the intensive study by various geological, physical, and other methods of *all* earthquakes in a restricted seismic province, *merogeoidal* or "regional" seismology. While the terms, hologeoidal and merogeoidal, have merit and deserve adoption they are new, here used publicly for the first time, and on this occasion the less satisfactory prefixes, "world" and "regional" probably will be more easily grasped and understood.

The chief work of hologeoidal or "world" seismology has been the mensurable instrumental registration of strong or world-shaking earthquakes, together with other earth vibrations or earth distortions of world-wide occurrence or non-provincial character. It seeks to advance knowledge (1) concerning the

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radiation of seismic energy through the earth and the transformations which this undergoes, the bearing of these transformations upon the interior condition and constitution of the earth (its elasticity and density, and their variations), its state and history of strain, and the characteristics of seismic wave-motion in it; and (2) in the discovery and delimitaton of provinces of high seismicity (which are regions of overstrain), especially in remote areas, and under seas. The geographic distribution of these, their degree of activity and its frequency, and their relationships to structural geology on the grand scale is of high importance in geotectonic geology, but all this has also an important seismologic aspect *per se*.

The student of "world" seismology, therefore, is keenly interested in the domain of the Pacific because here is the source of a great part of all his fundamental information, whether of instrumental or other kinds. But his interest in this is not primarily geographic. Usually he is not interested in the seismological problems of the Pacific *as such*.

He recognizes, of course, that this great zone of lands bordering the ocean is a complex of "regions" or provinces some of which overlap geographically, though distinguishable from each other in their time-cycles of activity. He sees, too, that there are hiatuses in the zone, as in Panama, where no earthquakes of consequence have occurred in three hundred years, and in the region about Puget Sound where shocks of any sort have been rare since we have known it. (These hiatuses may not be real, but only apparent. Our historical accounts of Panama, and other districts, cover only a short duration. Some shocks have occurred in both these provinces. Therefore these may be dormant areas only.) But, however this may be, and though, in fact, the Pacific zone is a complex of distinguishable provinces, the student of "world" seismology is interested in it chiefly as a whole, as a major geotectonic feature of great significance in a consideration of the framework of the earth and as the source of great disturbances whose vibratory phenomena enable him to probe into the conditions which prevail deep within the earth.

In this connection, just in passing, a brief statement may be made for the benefit of the technical students present, touching recent work by Adams and Williamson of the Geophysical Laboratory of the Carnegie Institution of Washington. It will be recalled that a group of German seismologists, centering around Wiechert, some years since reached the conclusion that the interior of the earth could be divided into several

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concentric shells possessing different coefficients of elasticity and density, and that these shells could be distinguished rather sharply. Adams and Williamson have recently reviewed this work and have shown that, if the determinations of the arrival-times of the chief wave phases previously utilized were in error no more than two or three seconds (an amount very close to the likely error in measurement on ordinary seismograms, to say nothing of several other probable sources of error, such as clock error, parallax error, instrumental lag, and the like), a curve which shows no cusps can be drawn to represent the variation in elasticity and density downwards toward the center of the earth. Such a curve is more probable *a priori* than that drawn by the Wiechert school, and it appears to fit the present facts of measurement quite as well. This affords a picture which does not call for sharply distinguished earth-shells of markedly different physical properties.

This work of Adams and Williamson does not affect the hypothesis that there is a weak layer at small depth postulated in the geologic philosophizing of recent years and strongly sustained by geodetic findings, and by recent seismometric findings too, nor the interpretation that the central core of the earth, for a little less than half of its radius, is in a state which does not transmit transverse wave-motion readily. This latter remains one of the puzzling findings in physical seismology. These workers have simply eliminated the requirement of sharp transitions in density and elasticity from one depth shell to another immediately subjacent.

To return to the subject. For the requirements of hologeoidal or "world" seismology in relation to the Pacific what appears to be needed for the triangulation of great earthquake origins situated about its margin is a sufficient number of adequately equipped stations situated in the continental areas and back from the circum-Pacific coastal zone. Preferably these stations should have like equipment, and be thoroughly coördinated. It should be recognized that stations located in the active seismic zone, or inside the ocean basin, are not well placed in general, for this work of triangulation.

But there are other reasons why such stations are useful. Honolulu, for example, though not a good site for service in the triangulation network, is an admirable place for a station of the first class for the study of seismic wave speeds in various suboceanic directions, for the study of microseisms, earth-tides, and many similar sorts of fundamental research in hologeoidal physical seismology. As we shall see, it is a good place also for the conduct of certain "regional" studies.

Before leaving the "world" aspect of seismology reference must be made to the status of relationship between great earthquakes and volcanic activity. For this has been touched on loosely several times in other meetings of this Conference. Regardless of earlier prevailing views, and regardless of coincidences however plausible, one of the few things that can be

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stated authoritatively is this: all present knowledge and evidence strongly indicates that there is usually no immediate, or definite, causal relationship between these phenomena. Further, there appears to be no *immediate* connection between great earthquakes of nearly contemporaneous occurrence in parts of the world far separated from each other. And it is even probable that many so-called "volcanic" earthquakes are due to ordinary non-volcanic causes. But at the same time, despite this sweeping denial of any *immediate* causal connection, evidence accumulates and the suggestion grows in force that there is some *ultimate* fundamental causal connection between seismic and volcanic action, and, too, between contemporaneous great shocks at points far remote from each other. Merely to illustrate, these phenomena may be common, though immediately different, responses to earth-strain, relieved, say, (1) by viscous creep and flow, stopping and eruption in some cases; (2) by elastic strain, fracture and faulting in other cases; and (3) in still others by a combination of these mechanisms. The latter sort may after all prove the more numerous, but this cannot be said to be the present indication. Consideration of these fundamental relations is one of the most fascinating occupations in geophysical science.

THE PACIFIC ASPECT OF "REGIONAL" SEISMOLOGY

As mentioned earlier, the great Pacific seismic zone is made up of distinguishable regions, fields, or tracts. Any attempt to break up such a zone into its component parts finds certain of them overlapping each other, and these are then distinguishable in the overlapping parts only in respect to their time-cycle of activity. For example, in one such tract strain is accumulated until finally it is relieved by a fault-slip. Later similar action occurs in a neighboring tract. A certain area is affected successively by both strains. It is common to both tracts. This is even more strikingly true when we consider the areas shaken instead of those severely strained. Yet the tracts are geographically distinct. And they may be wholly unrelated dynamically; that is, the strain in one tract may be due to immediate causes quite distinct from those operating in the other. Such close association of seismic regions, with overlapping in many instances, is found in Italy, in Japan, in California, and elsewhere. But the regions or provinces are distinct, nevertheless, and behave for a time as units, even though they may not in all cases be delimited sharply. It is the intensive and systematic study of *all*

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shocks in such limited regions, or groups of regions closely associated, seismic provinces, which constitutes "regional" or merogeoidal seismology.

The "regional" study of earthquakes comprises two programs, A and B, of which A is ordinarily much subordinate to B in actual importance, though at crises the predominant program.

A. The investigation of great earthquakes in the region of their occurrence: (1) from the strictly scientific; and (2) from the practical point-of-view. These, of course, are inextricably intertwined.

1. On the scientific side, observation of the phenomena in relation to the structural and tectonic geology of the region, and its bearing on geological dynamics in the province, as well as in the geoid, is required. This involves the examination of permanent effects in soil and rock and in structural works, and transitory effects also when this is possible, both of primary and secondary character, such as shearing rifts on the one hand, and disturbed natural basins of water-logged alluvium on the other, together with structural characteristics.

2. On the economic and humanitarian side the investigation of damage is required, its causes, from both the natural and the structural point of view, and its geographical distribution, all in relation to the underlying geologic structure, and in relation to surface developments and their bearing on living conditions (as sites for buildings, routes for transportation or conduits, and so forth), and the study of the problem from the point-of-view of engineering science, education, protective legislation and insurance.

Really powerful earthquakes occur only at considerable intervals in a given province. Hence the studies embraced under sub-program A must always be sporadic and occasional, and must comprise special inquiries limited in the first instance to a partial range of phenomena associated with particular shocks. Therefore, beyond a general plan of attack, a suitable financial reserve, and a ready assembly of necessary transportable equipment, little preparation can be made for the work of this subprogram. Consequently, it must be held subordinate in importance to the work of the sub-program B.

B. The systematic investigation of small earthquakes, and related vibratory motion and distortions, in relation to the prov-

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inces in which they occur seems the most important program in regional seismology, or in seismological science generally. By far the most emphasis must be placed upon it here.

This requires a continuous program of work and involves a variety of methods, some of routine character but all with a definite investigatory and research aim.

Besides its scientific aims, within the province and for the geoid, too, this work has important economic and humanitarian ends.

In the first instance, and chiefly, so far as methods are concerned, such intensive study of small earthquakes, and similar strain phenomena, is related to the individual geologic and physiographic characteristics of the local province in which they are conducted; and in detail they must be controlled by this. So procedure may differ somewhat in different provinces, and no general plan adapted to all provinces can be outlined. Even in the matter of instrumental equipment different mechanisms are very likely desirable in different provinces. This work is primarily research and individual, as distinct from standardized or routine attack is requisite.

The immediate purpose of the study of earthquakes in restricted provinces is the discovery and location of regions of rapidly growing strain, or places where strain is already in a critical state, in the rock crust; and the elucidation of the mechanisms and laws of its growth and relief. This calls for three plans of attack.

1. Mensurable instrumental registration of every shock, down to the very minutest ones, which occurs within the province is required in order to determine as well as possible: (a) the geographical locus of its epicenter; (2) its depth of hearth, and (c) the shape, size, attitude, and the time-space mode of development of the causative origin, and whether or not a fracture or fault-slip.

Furthermore, the radiation of vibratory energy through the strata of the region and its transformation and absorption, as bearing upon the adjacent elasticities and structures, requires as adequate registration and analysis as means allow. In this connection the determination of the speeds of radiation through superficial strata, and the registerable distances, in the case of shocks of small original energy constitute one of the most important problems in regional seismology, for most origins can

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only be discovered by the instrumental method as the shocks are usually too weak to produce characteristic surface effects and many of them even are imperceptible to the human senses. Many zones of origin have no clear surface indications of geologic character, and many are buried altogether.

Since the smaller shocks do not transmit detectable amounts of energy to great distances, the registering stations, to perform the services required of them, must be spaced relatively closely, at intervals in a triangular network not greater than 100 kilometers and preferably not greater than 50 kilometers, perhaps more closely still.

2. The specialized study and survey, from the seismological point-of-view, of geological faults and highly contorted folds, and especially of the recognizable surface criteria of known active faults, with the application of this knowledge in the search for others not yet known or delineated.

The location of active faults and of certain neighboring conditions, such as basins of water-logged alluvium, is necessary to predetermine places of special danger. The practical importance of this needs no emphasis.

Obviously the instrumental findings must be correlated with the field studies: (a) to verify the present activity of recognized faults; (b) to discover localized overstrain, especially near its crisis, upon segments of these faults; and (c) to discover, by the clustering, or specialized distribution of epicenters, previously undiscovered active faults and the places of overstrain along their courses, especially when these are buried faults. In all this we are seeking to learn "the laws according to which faults grow."

The forecasting of (a) place and (b) time of shocks, though not now realizable, is not a hopeless prospect. It is a most important purpose of such work in future. This was the subject of an excellent paper by the late G. K. Gilbert[1] and it has been touched upon in numerous other places.

Since geological fault movements have been actually observed to occur great enough to disturb the control-points in systems of primary and secondary triangulation, for practical reasons, as well as more fundamental ones, precise geodetic observations are indicated as part of the program of investigation.

All this must lead to critical experimentation, the course and goal of which cannot be foreseen wholly.

[1] Gilbert, G. K., Earthquake Forecasts: Science, Jan. 22, 1909.

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3. This leads at once to the improvement and development of instruments, both for the routine registraiton, and for special studies. This is one of the most urgent needs.

The first and most important need is a seismometer for local earthquakes. No suitable mechanism has yet been devised which is well suited for the continuous registration of small, or great, local shocks. The requirement for this, indispensable to progress of the kind sought, is continuous registration with a sufficiently "open" time-scale to permit analysis of the resulting seismograms, involving short wave-periods, a great range of amplitude, and short time-intervals between phases. Moreover the instrument must be sensitive, and respond with an adequate degree of precision, to vibrations of very small absolute amplitude, for shocks far too weak for perceptibility by the human senses greatly outnumber perceptible ones, at least in some provinces. And it is precisely these weak shocks which indicate growing strain and precede the failure and faulting which produces strong shocks. The accurate location of all these is the prime requisite in the attack upon the geodynamical problem whether for fundamental scientific or immediate practical reasons. The purpose, then, of "regional" investigation in seismology is to learn the causes, distribution, and behavior of strain and shock in a local province, and to apply this knowledge to the economic and humanitarian problems there. The general scientific bearing of the work is obvious.

The application of some of these methods for "regional" seismology, showing how sharply it is thus distinguished from "world" seismology, may best be illustrated by the discussion of particular provinces. Two of these may be touched on here, California and Hawaii, both involved in the Pacific complex. This requires description and discussion of the local phenomena. It will illustrate also the individual character of the different provinces.

THE CALIFORNIA PROVINCE

The great shock in California in 1906 was caused by a fault-slip which visibly cut the surface near and nearly parallel to the coast line for a distance not less than 180 miles and possibly as much as 300 miles. As drawn on a map, an S-shaped segment of the fault, wholly outside the coast line, is hypothesized to connect a segment near Cape Mendocino with the major segment farther south. In reality this curved part may not

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exist. The Mendocino segment may belong to another fault east of and parallel to the chief one. This is not certain, but it is clearly suggested, and it is supported by certain features found in the field.

Beginning about 1850 work of triangulation was undertaken by the U. S. Coast and Geodetic Survey in the central California region and was conducted at irregular intervals. Upon resuming work in 1872, after an interval during which the strong earthquake of 1868 occurred, discrepancies were found which at that time were attributed to errors in the previous work, despite strong counter claims by the earlier observers. But when the 1906 earthquake had demonstrated significant surface displacements large enough to affect the triangulation network (offsets as great as 21 feet in soil and 15½ feet in rock were observed) a re-survey was immediately undertaken. This was completed in 1907. As a result of the reconsideration of all the surveys, *two* stages of earth distortion were found, one apparently related to the 1868 earthquake and one to the 1906 earthquake. It is inferred that in each instance there was a slow distortion of the surface in the nature of a shear followed by a sudden rebounding readjustment, involving marked relative displacements and offsets, at the time of the fault-slipping. Obviously these circumstances visualize clearly a mechanism of causation, and suggest a method (the survey and frequent reëxamination of lines of sight and of precise levels), of detecting and measuring progressive distortion of the surface, thus pointing in advance to places of growing strain where great shocks must eventually occur to provide relief. This, obviously, is a method applicable only in "regional" seismology.

This Central California region is complicated. The 1906 shock did not originate on the fault which produced the 1868 shock, but on another parallel to it, the earlier slip occurring east of San Francisco Bay and the later west of it. Both fault-slips intersected the surface and both fault zones are characterized by similar surface peculiarities, little basins, pools, hummocks, and minor escarpments jumbled irregularly together in and along a narrow tract, the fault zone, all of which are mostly unrelated to the immediately subjacent rock structure or to the larger features of the land topography. Thus is formed a recognizable topographic ensemble characteristic of active faulting. Both the movements referred to exhibited predominant horizon-

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tal shearing which has here controlled the critical topographic development. Here, then, is another subject for study, and another basis for a distinctively "regional" seismologic method.

The history of earthquake occurrence in Central California and the geologic record as well, indicate that many strong and destructive shocks have been caused here by fault-slips like those on the occasions cited. Many of these were of very great energy. And, indeed, there is suggestion that the shock in 1868 was of greater energy than that in 1906. For example, though Mount Tamalpais lies nearer to the fault active in 1906 than to that active in 1868 it was transplaced six feet northward in connection with the 1868 earthquake while with that of 1906 it was transplaced only two feet to the southeast.

From 1769 until 1857 Southern California was the scene of several earthquakes of great power, many moderate ones and countless small shocks. The very great shock of 1857 apparently brought temporary relief to the district and few shocks occurred there for many years thereafter. A moderate shock occurred in 1899, but quiet again followed until 1915. Since then several strong shocks have occurred there, originating on different faults, and indicating that widespread overstrain has again accumulated there.

A great number of active faults are involved throughout the California province, making the region one of great seismic and tectonic complexity. Its study thus requires a considerable variety of methods few of which have been developed in connection with "world" seismology.

THE HAWAIIAN PROVINCE

Turn now to Hawaii, where there is only one historic record of a destructive earthquake disturbance, that of March and April, 1868. (The California shock of that year was in October and was wholly unrelated to that in Hawaii, except that the year 1868 was unusual in the occurrence of numerous great earthquakes, which may testify to an unusually great world-wide strain then superposed on the critical local strains of many regions.) The Hawaiian shock of 1868 was one of great power. Fresh rifts were rent open on Mauna Loa and on Kilauea from summit to sea in directions trending southwardly from the craters, producing relatively simple linear systems of fissures which remain open and visible to this day. A tidal wave more than 60 feet in height swept the whole southeast coast of the Island

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of Hawaii, and produced pronounced undulations of the sea on the shores of all the Hawaiian islands, especially on Maui, where perceptible disturbances recurred as many as thirteen times. The southeast coast of Hawaii all the way from the East Point to the South Point subsided by amounts varying up to a maximum of seven feet. Though this is the only great shock thus far recorded in Hawaii there is geologic evidence of many others. This event testifies to great crustal strain relieved by fracture and faulting. The volcanic manifestations which accompanied it were wholly subordinate in energy.

In 1912, when the writer was brought to Hawaii to study the small earthquakes which are so frequent on this island, it was with a hypothesis in mind that these shocks, occurring in close proximity to an active volcano, probably differed in mechanism and causation from those in such regions as California. But in the course of this study it became evident that the small shocks recorded at the seismograph station originated at distances considerably greater than the distance to the active pit, Halemaumau, about two miles west. Very few shock origins were distant less than five miles, while the vast majority fell into two groups, a greater group distant between 15 and 25 miles and a lesser group distant between 30 and 40 miles. These distances are too great for the shocks to be ascribed to origins deep beneath Halemaumau, unless our views of the causation of "volcanic" earthquakes are to be changed in very radical and seemingly unreasonable ways. For a good many reasons it seems exceedingly improbable that any considerable percentage of the shocks measured emanated from the axis of the active pit-crater. Not a single one could be definitely located there. Many of those associated with the 1916 eruption of Mauna Loa certainly originated in fracturing and slipping in the zone fissures on the south flank of that mountain.

Let us, then, look at Hawaii from the tectonic standpoint. Southwest, and then south, from Kilauea through the Kau desert runs a great system of visible fault fissures. Though the land is jungle, there is strong reason for believing that a similar system runs northeastwardly from the crater. Another system, less well marked, extends from Halemaumau, through Kilauea-iki into the jungle. One curving system (or two intersecting rectilinear systems) extends from Halemaumau through Keanakakoi on along the line of small craters through Puna to the

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sea near the terminus of the 1840 lava flow. Through Mauna Loa from its crater southward to the sea and northeastward to the jungle (and presumably to the sea also) runs another major system of visible fault fractures. The cliffs of the southeast shore are known, since 1868, to be escarpments of a great active fault system. There is strong suggestion of other zones tangential to the island. The cliffs at Waipio and the great deep to the northeast suggest a great fault system along the northeastern shore. Its bold topography suggests that the western slope of Mauna Loa, in line with certain features on Hualalai, is the result of faulting. This is strengthened by the events accompanying the submarine eruption in 1877.

These numerous fault systems, together with the origin distances of shocks found by seismometric reduction, strongly suggest that the mechanism of causation of the shocks in Hawaii may not be different from that in other lands. As yet this should be considered only a working hypothesis. But it does indicate the need for a "regional" study of shocks in Hawaii involving many methods some of which are unknown to the routine of "world" seismology. In Hawaii we seem not to be dealing with a simple explosion center for volcanic causation.

The "regional" problem in Hawaii, then, requires first, the determination of the places (and depths) of origin of all shocks, utilizing for triangulation data obtained at an adequate number of suitably equipped stations, and the correlation of these shocks with faults or other loci of causation; second, study of the characteristics of the fault outcrops which in Hawaii are visibly different from those in California; third, survey and watch over lines of sight and levels, or systems of triangulation, in order to detect strains or warpings; and, further, such special research programs as are suggested or necessitated by the other findings, or by the peculiar local conditions which prevail in the province. Not merely the island of Hawaii is concerned, but all the islands of the group. No one of them is wholly free from the occurrence of small shocks.

Enough has now been said to illustrate the difference in aim and method between "regional" and "world" seismology, and how each of these grand divisions of the science is applicable in the Pacific domain.

Especially in regional studies do we wish to determine the places of critical overstrain, and so to discern in advance where

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powerful, relieving shocks will originate and what the symptoms of their approach are: for though they cannot be prevented, preparation can be made for them. In language suggested by the comment of a sarcastic editor upon the value of seismographs, we want to study the behavior which indicates that the mule is getting ready to kick, rather than the bruise which results. Hitherto the bruise has had the chief attention. As the writer sees it, the beginning of work in regional seismology in certain Pacific provinces is an immediate, urgent need, not, to be sure, for the reason recently cited in the case of Polynesian anthropology, because the fundamental data are on the way to disappearing forever, but because the cycle of action in most provinces is long,—far too long to be compassed in a scientific lifetime. It requires, therefore, intensive, systematic work, long continued through the coöperative endeavors of a staff of investigators. It cannot be entered upon too soon. Delay is dangerous. Significant events, fundamental to an understanding of the cycle, may pass unobserved, and, once past, these will not recur for many years. For example, only one great earthquake is on record in Hawaii. Yet its phenomena throws much light on the mechanism of action here. Had it occurred before 1820 we would not know of it and our understanding of seismic activity here would be correspondingly imperfect. We do not know how soon the next great shock will come. In Jamaica, Port Royal was destroyed in 1692 with accompanying phenomena of a most enlightening sort, and in 1907 Kingston; more than 200 years elapsed between catastrophic shocks in the same tract. Like the great shocks the small shocks have meaning. They should not pass unobserved.

In brief, "regional" seismology aims to investigate the distribution and behavior of strain and shock in relation to the geology and works of construction in a limited province; while "world" seismology aims to determine the distribution of regions of high seismicity (or strictly of great earthquakes) to observe and measure the behavior of seismic waves as these traverse the earth, and to find the interpretation of this behavior. The domain of the Pacific is a fruitful source of data, valuable alike for scientific and humanitarian reasons, in both divisions of the science.

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DISCUSSION

MR. VAUGHAN: Is Panama considered one of the regions that is an earthquake hiatus? After I left Panama in 1911 an earthquake occurred causing uneasiness to the engineers of the canal. A break occurred near a deep in the ocean and broke the cable.

MR. WOOD: No region has a total absence of earthquakes. Panama as well as British Columbia are each a hiatus in point of time rather than of geography. In British Columbia there is no record of destructive earthquakes.

MR. MAYOR: We appreciate the importance of local studies of earthquakes. In Kingston, Jamaica, the area that suffered was the soft ground, the "made ground" near the shore. The houses built on rock withstood the shock and remained intact so far as their construction was concerned. I have just looked over the seismographic laboratory at Samoa, now under New Zealand, which may or may not be retained by the government. It is important to have it kept up, for tidal waves and probably submarine eruptions occur in that region. Pumice has been found covering the surface of the sea near Samoa. Important earthquakes occur in American Samoa, giving rise to tidal waves; a destructive one occurred in June, 1917. There the earthquakes do not take place in the immediate neighborhood, but arise in the Tongan Deep. The wave in 1917 was 40 feet high. Recently at Pago Pago an earthquake was followed in half an hour by a wave.

MR. JAGGAR: The Section on Volcanology and Seismology has passed a resolution recommending a continuance of the New Zealand observatory. The New Zealanders are solid for the support of Dr. Angenheister who has carried on the work throughout the war for the sake of science, also doing work in terrestrial magnetism. He is a pupil of Wiechert. The importance of the work has come out in statements of Mr. Littlehales, Mr. Wood and Dr. Mayor. The whole South Pacific needs more study, as many tidal waves and eruptions occur that we never hear of. It is also the center of the coral reef problem and has to do with the heaving up and settling of continents, a subject that all naturalists are interested in.

MR. WASHINGTON: Adams and Williamson have studied the earth's interior in connection with earthquakes and the compressibility of rocks under controlled conditions. They find that rocks are not compressible to such an extent as will account for the high density of the earth. They have calculated roughly that at the core the specific gravity should be about ten times that of water. Their idea is that the zones from the surface rocks to the center are not sharply divided, but are transitional. There seems to be a rigidity change at a depth equal to about half the earth's radius.

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PULSATORY OSCILLATIONS IN RELATION TO OCEAN WAVES

By Fusakichi Omori

NATURE OF MOTION

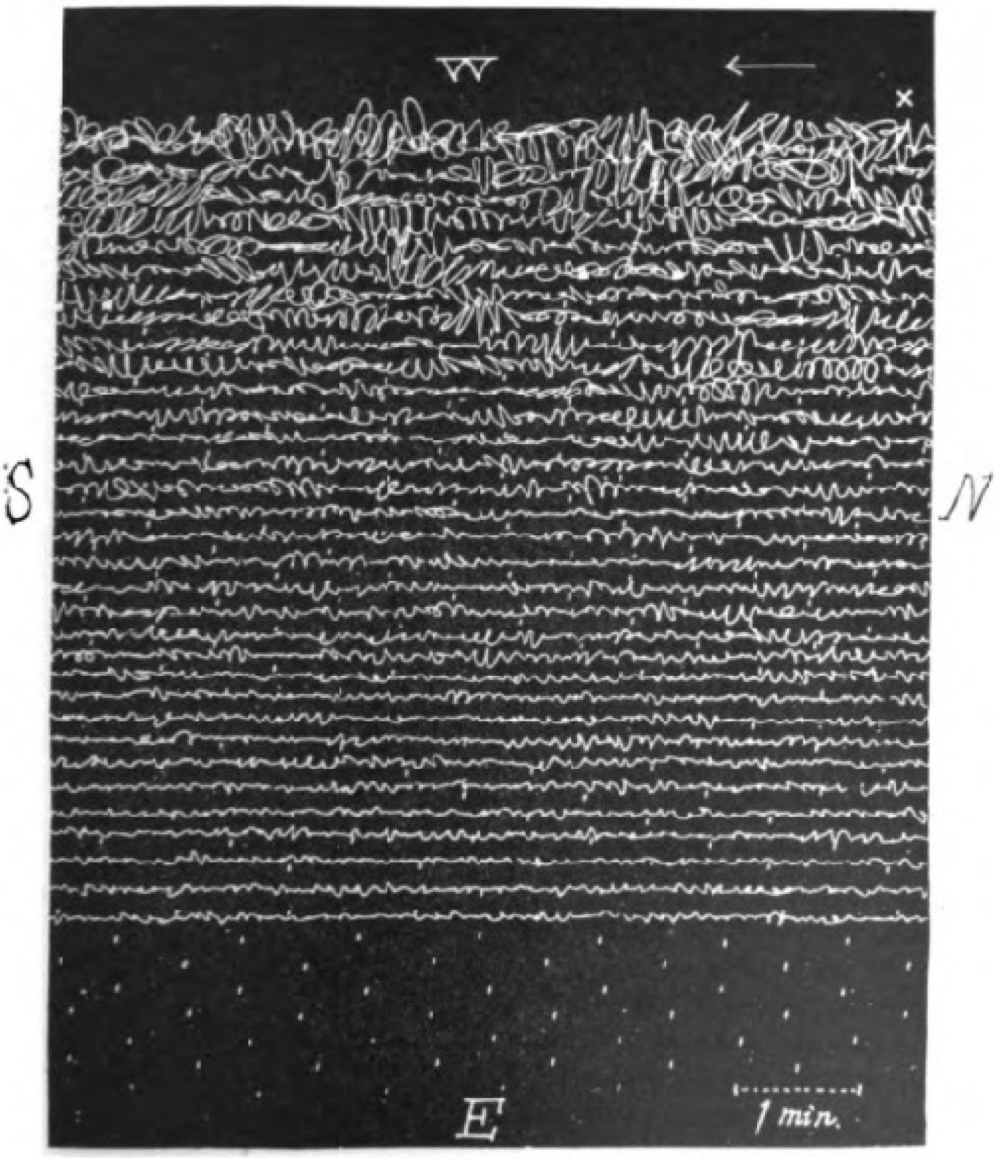
Pulsatory oscillations, generally but erroneously known as microseisms, are small, slow, unfelt, non-seismic movements of the ground, which with alternations of maxima and minima continue for several hours or for several days, the average periods being either about four seconds or about eight seeconds. They attain full development on extensive planes of new formation, such as the regions about the cities of Tokyo and Osaka, the range, or double amplitude, being often greater than 0.1 mm. On mountains, the motion is much smaller. Again, pulsatory oscillations are due to no tilting of the ground, but are rectilinear, to be decomposed into three rectangular components, of which the vertical is often well pronounced. The pulsatory motion at a given place is constantly changing in direction, according to the observations in Tokyo, and the individual vibrations can not be identified at two observatories a few kilometers apart, indicating that these are not of the nature of progressive waves radiating from a single origin.

RELATION TO OCEAN WAVES

Pulsatory oscillations occur invariably with stormy seas. In Tokyo, these movements often begin several days in advance of the actual arrival of a deep barometric depression. As an example, I may refer to the severe Japan storm on Sept. 17. 1904, which indicated the minimum barometric pressure of 724 mm. at Ushio-misaki, the southern extremity of the peninsula of Kii, at 2 a. m., and which crossed the Main Island between Osaka and Kobe. It was preceded by quiet weather on the 14th and 15th; the depression center of 725 mm. barometric pressure having made its appearance off the southwest end of Kyushu first on the 16th, at 6 a. m., when a storm warning was issued by the Central Meteorological Observatory. The tromometers in the Tokyo University, however, had already indicated distinct pulsatory oscillations at about noon, on the 12th, which were much intensified on the afternoon of the 14th and attained the maximum stage between 4 a. m. on the 16th and midnight of the 17th.

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FIGURE 1. Duplex pendulum tromometer diagram of the large pulsatory oscillations observed in Tokyo, October 6 and 7, 1919. Magnification = 20.

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Again, it often happens that in a harbor or bay the weather remains quiet, while off the coast or on the outside ocean surface the waves are so rough as to render navigation dangerous for small craft. On such occasions the tromometer record of pulsatory oscillations serves as a faithful indicator of the condition of the sea. Thus, the numerous fishing boats which had sailed out of the harbor of Choshi on the morning of March 12, 1910, when the weather was fine, met heavy seas off the coast, resulting in the loss of several hundred lives. According to the tromometer registers in Tokyo, the pulsatory oscillations gradually increased in amount from about 4 a. m. on the 12th and remained most active between 1:30 p. m. on the same day till about noon the next day, the range of motion in the east-west and the north-south components being each equal to 0.2 mm., and that of the vertical component about 0.3 mm.

OSCILLATION PERIOD

To deduce the average periods of the sea waves, the direct observations and automatic large time-scale registrations with portable mareographs have recently been made at several places along the coasts of O-shima (Izu), the Kazusa-Awa peninsula and the provinces of Sagami, Suruga and Totomi. By way of reference some measurements were also made of ships' rolling in the bays of Ise and Tokyo and also on the Pacific off the coast of Tokaido. The wave period most commonly found in the bays was 4.4 sec., while those predominating along the stormy open seacoasts were 7.6, 11.1, and 15.4 sec. Among the lower periods, that of 65.5 sec. was well pronounced. These different wave periods are very nearly equal respectively with those relating to the variation of the wind pressure which I have found from an examination of the large time-scale pressure-tube anemometer registers made during storms by Mr. Shimono and Mr. Asakra at Osaka and Yokohama meteorological observatories respectively. (See table 1.) Among the others, the periods of about 4 sec. and of about 8 sec. found for the sea waves and the wind pressure variation may be assumed to be identical with the two fundamental periods of pulsatory oscillations. In other words, the sea waves are surface disturbances principally due to changes in wind pressure, which, imparting an incessant series of impetuses on the ocean bottom, cause the neighboring area of the earth's crust to assume the pulsatory motion with similar periods.

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TABLE I. RELATION OF WAVES TO WIND PRESSURE

Period of oceanic waves; observed along Pacific Coasts of Japan.	Period of wind pressure variation; observed in Yokohama and Osaka.
4.4 sec.	4.4 sec.
7.6	7.9
11.1	10.6
15.4	17.2
23.6[1]	27.5
65.5	61.2
112.0[1]	117.0
	253.0

[1] Not well-pronounced.

PULSATORY OSCILLATIONS IN RELATION TO TYPHOON TSUNAMI

Mere strong winds form no cause of pulsatory oscillations. Thus, on March 15, 1910, very strong southerly winds blew in Tokyo, which broke a wooden telegraph post in the Yotsuya district. Yet the pulsatory oscillations on the same day were not specially large, the range being less than 0.04 mm. Generally the southerly winds produce in Tokyo only slight pulsatory motion, as in that case the storm center is passing over Japan Sea at a distance from the city in question, in which swells are probably not so huge as on the Pacific. Again, when a storm center passes across, or very close to the Pacific coast of the Main Island (Nippon), the fall of the barometric pressure on land may be excessive, and yet the pulsatory oscillations in Tokyo do not develop beyond a certain limit, say 0.1 mm. Such is the case when a storm (typhoon) produces a *tsunami* or tidal wave in the bay of Tokyo. On the other hand, when a storm is rushing over the ocean off the Pacific coast, the barometric fall at the center must be excessive, as no irregularities such as are found on the land surface present obstruction to the fury of the typhoon. The consequent development of pulsatory oscillations is very marked, those observed in Tokyo on Nov. 17 and 18, 1900, and on Oct. 6, 1919, reaching respectively 0.65 and 0.85 mm. in each of the east-west and north-south components. In such cases the sea water is attracted toward the storm center, so that there is no tendency toward its accumulation or elevation along the coast; a *tsunami,* or tidal wave, being consequently not produced. Thus, the observation of the pulsatory oscillations, coupled with an accurate determination of the rate and route of the storm center across the land, may give a timely warning of an approaching typhoon, *tsunami*, for places like Tokyo or Osaka.

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DISCUSSION

MR. WOOD: The data presented by Dr. Omori should be of interest to meteorologists.

MR. JAGGAR: Heavy microseisms are frequently recorded at the Kilauea station when in the autumn the trade winds are replaced by prolonged calms. These heavy microseism storms show resonance effects with fluctuations in amphitude, and apparently are distinct from the irregular and very intense vibration which occurs during a heavy wind storm at the station. There is no evidence during the calm spells that a heavy surf is breaking on the shores of the island of Hawaii.

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STATUS OF THE SEISMOLOGICAL WORK IN THE PACIFIC

By Otto Klotz, Director Dominion Observatory, Ottawa, Canada; President, Seismological Society of America

(Presented at the request of Committee on Program.)

INTRODUCTION

What follows is based on available material in the Dominion Observatory at Ottawa. I am stating this in justice to myself and to forestall criticism concerning material with which the observatory has not been supplied.

The great want in seismology is coördination and standardization. We have different instruments, different methods, different interpretation of seismograms; we have no working plan save merest routine, no definite problems, no directing force or body or committee. We are simply seismological entities more or less aimlessly floating through space, constrained neither by the gravitational nor any other law. Seismology with one or two notable exceptions has been up to the present a by-product in the activities of some men of science. Seismology deserves the undivided attention of capable men who can grapple with the many problems presented both by the instruments and by their records, followed by the highly important investigational work in geophysics. The field in seismology is at present almost a *tabula rasa.*

It goes without saying that reliable seismograms furnish the data for all our computations about an earthquake: its location; its hypocentral energy; its intensity at the various points of observation; the speed of propagation of the various waves, involved in which are the elasticity, the density and rigidity of the material along its path; the coefficient of absorption; in short, the seismograms give the story of the earthquake, just as the spectrogram gives the story of the distant stars. But are our seismograms reliable? There's the rub. Unfortunately, the earthquakes do not behave as we want them to do. We want one momentary, instantaneous cataclysm, like the two Mexican earthquakes of March 26, 1908. Frequently, however, the breakdown is not instantaneous and less distant stations may receive

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a first impulse that is absorbed before it reaches a more distant one, so that the phases read as P are not identical.

Now some remarks about seismology in America, and in what direction its efficiency may be increased. According to the published list (Bull. Seis. Soc., vol. 1, No. 4, 1911), there are seventy-two seismological stations of the first and second order in America of which forty-five are in the United States and five in Canada. This is quite enough for the study of the larger questions in North America, but their distribution is not the most favorable for research. The distribution should be based to a great extent, although not wholly, on the idea of seismic triangulation. For this reason there should be stations at Helena, Port Nelson, Unalaska, Dawson and Nome, supplied with instruments to record all tectonic earthquakes. Men in charge of such stations should be given opportunities to visit other stations where similar instruments are installed. A thorough understanding of the instruments employed is essential.

TIME

Although great improvements have been made in the time record, a satisfactory stage has not been reached. It is to be regretted that manufacturers of seismographs generally furnish a cheap clock for recording the time. This is a mistake. With telephone, telegraph or wireless available, a daily clock correction should be obtained and tabulated, entered on each sheet and applied to the seismogram readings *before* they are sent out, not a month or two *afterwards*, as was done by some European stations. For the interval of time, the different phases and the determination of the distance from the stations to the epicenter, the clock correction is of course not necessary, but when we wish to deduce the absolute time of the occurrence of the shock, at the epicenter, it is essential that the time of each station be expressed accurately in Greenwich Mean Time. We emphasize, therefore, that each station should strive to have its time accurate to within one second, a not unreasonable request.

INTERPRETATION

Let us assume that the two preceding subjects, instruments and time, have been satisfactorily dealt with, so that we examine our seismogram with a certain degree of confidence. A tectonic earthquake has been recorded. We see the beautiful and regular sinusoidal waves and know that we are dealing with a severe

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shock. Unfortunately those fine markings are of no immediate concern to us. They will be later if we wish to evaluate the energy liberated by the earthquake. Our first concern is to find P. If there are no microseisms present, there may be little difficulty in finding a sharp offset from the straight line showing rapid oscillations of a second or two or less. In this case we feel sure of our P. When micros (microseisms) are present the reading is not so simple. However, as the period of P is in general less than that of the micros one will generally find a tiny peak superimposed on the sinuous micros and thus locate P. But all this must be done with circumspection, and the congruity of P, S and L, if possible, established. If the earthquake is a clean breakdown of a sudden adjustment of the stresses, then PR is frequently found soon after P by an increased impetus. We must remember that after the first arrival of the P waves others follow and a medley of waves is set up that continue till the L waves are well in the saddle and all traces of P and S waves have disappeared. This medley militates against accurate interpretation. Naturally the P wave entering upon a quiescent state of the seismograph is the only one that lends itself to absolute accuracy of a second of time. The S wave enters its phase while the effect of P waves is still at work, and hence the S is often not so sharply defined as the P.

The greatest uncertainty, however, occurs in identifying the beginning of the L waves. There is no trouble in seeing L waves, but when we trace them back we almost invariably get into a region of uncertainty. This uncertainty is and must naturally be confined within certain limits in order to be consistent with the readings of P and S already made. Perhaps these latter may require re-reading and revision for we must remember that there must be consistency within certain limits, based on our experience and tables. (These latter, it may be stated here, although not perfect nor final, are pretty good, as shown by their application to many seismograms and the results deduced.) It has been our experience that in general the periods of the L waves decrease with the lapse of time. Frequently the L waves start with a period of 40 seconds, which quickly dies down to 30, 24, 20, down to 12 or so, and may be resuscitated for a short interval to a longer period, say 20-24, when L R appears in a heavy shock.

Having read P, S, and L we have the data for our immediate concern. We have yet to read the maximum amplitude of

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our two components. Here we must confess is undoubtedly the weakest part of our interpretation. This amplitude is supposed to be some function of the energy. It is only necessary to look over the reports from various stations to see that something is wrong, for we find stations at great distance from the epicenter, report amplitudes far in excess of those much nearer, which on the face of it is untenable. Furthermore the relation that exists between the magnitude of the amplitudes for the two components N-S, E-W, and the direction from the epicenter is not at all apparent, as is the case with the amplitude of the first impulse of the P wave and upon which Galitzin based his determination of the position of the epicenter, combined with the evaluation of Δ from S-P. We know, or believe we know, the free period of our pendulum; we believe we know the damping ratio; we believe we know the period of the earth particle, we then consult the "magnification curves" and find the ratio between the theoretical magnification, which perhaps we have ourselves determined, and the magnification for the case in point. We apply the latter to our seismogram and enter on our sheet so many microns amplitude. How near to the real truth this is—who knows? Here is room for investigation and improvement.

Let us return to the interpreted P, S and L. We turn to the Seismological Tables, which we believe are pretty generally used in America, and find first from S-P the appropriate Δ, and from another table the corresponding P-O, from which follows O, the Greenwich Mean Time of the actual occurrence of the earthquake. O should of course be the same as derived from all stations. Discordances between O's may be due to several causes. Firstly, clock correction; this would show itself to the full amount; secondly, inaccurate reading of P or S, or both, thereby affecting Δ and P-O; thirdly in case of a gradual breakdown where the first P does not reach very distant stations, hence the records of two stations may not be of the same phenomenon, although the interpretation of each is correct; and lastly, small differences may be expected, due to imperfections of the Tables, particularly when the distances exceed 10,000 kilometers. How closely the O's agree when the seismograms show well marked phases is shown by Berkeley and Ottawa records, where with several earthquakes during the present year, the difference of the O's was three seconds. Well may we marvel at the advance seismology has made! When stations nearly 4000 kilometers apart record an earthquake by different instruments; determine

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its distance; and give the time when it actually happened thousands of kilometers from either place within a few seconds, it is certainly gratifying. I think I am safe and correct in saying that when the observer has confidence in his interpretation of a seismogram, the discordance between such different O's, barring clock corrections, will fall within ten seconds. As is well known for distant earthquakes, say over 8000 kilometers, the horizontal component of the P wave is weak, and is frequently not recorded, the first to be recorded being probably PR, but interpreted as P with consequent wrong distance and wrong O. With severe distant earthquakes it is worth while looking for LR; we must remember that at the anti-epicenter, the antipode of the epicenter, the intensity of the waves is increased and they start on a fresh envelopment of the surface of the earth. Even if our reading of L is inaccurate to a few minutes, when we find LR, the difference in time between the two is the time interval for the distance 40,000—2Δ. Taking a mean velocity for the L waves of 230 kilometers per minute, we obtain at least an approximate value of Δ, so that we can reëxamine the earlier phases of P, PR, S, SR, and discover any glaring inconsistencies and erroneous interpretations. We may rest assured that the seismogram is always consistent within itself; it remains for us to interpret it correctly. Although there is a small margin to our present values for P. S. L. for any given distance, yet that has its limit, and we must avoid recording the impossible.

A subject requiring investigation is that of the M waves, or maximum manifestation of the L waves. Every observer has undoubtedly found that not every earthquake shows an easily discernible M, dismissing for the present the oscillations set up in the pendulum itself which of course would give an erroneous M. Should we be able to recognize in every seismogram for a tectonic earthquake a well-marked M? What relation is there in the time interval between the arrival of L waves and the M? Is the interval a function of the distance? How shall we interpret two M's: must there then be also two P's and two S's? What relation is there between the M and the depth of crust involved?

In the velocity graph published by Wiechert and Zoppritz in 1906, Angenheister's value for M is included. From it we find that the velocities of the L and M waves are plotted both as straight lines with an interval of 6^m 50^s or 410^s for a dis-

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tance of 10,000 kilometers; other distances in direct ratio thereto. It may be correct, is it correct? If a constant relation exists between the L waves and M, then we have an approximate value of the distance; the approximation depending upon the interpretation of both L and M. M certainly requires further interpretation and investigation.

EVALUATION

A violent surface earthquake or Bergsturz occurred in Pamirs on February 18, 1911. Galitzin undertook to evaluate its energy as manifested on the Pulkova seismogram, an account of which was published by the writer together with the Ottawa evaluation for the same shock in the December number, 1915, of the Bulletin of the Seismological Society of America. Later Navarro-Neumann similarly evaluated the Cartuja seismogram. The method evolved by Galitzin, or any other method, will furnish an inter-comparison of interpretation and measurements on the seismogram, and accuracy of the magnification factor employed; for the energy, E, found at the various stations must, as in the case of the O, be the same. The derivation of E is not quite as simple as that of O; this kinetic energy is one deserving of more attention by seismologists and geophysicists, for it is the most potent manifestation of energy that we experience on the earth. The evaluations would probably confine themselves to severe tectonic earthquakes whose records would give ample material for measurements. It is to be hoped that this hitherto unused part of the seismogram may find its place in the publications of stations. McAdie gives in his presidential address the energy of the great San Francisco earthquake as 316354×10^6 kilowatts (Reid), or 3.16×10^{21} ergs. For the above Pamirs earthquake the energy liberated was 4.3×10^{23} ergs.

NOMENCLATURE

The nomenclature by the International Seismological Association years ago is now pretty uniformly adopted. In our Seismological Tables an important symbol, O, the time of the earthquake at the origin, suggested to the writer by Professor J. B. Woodworth of Harvard, was incorporated and I am glad to see that in a report from Shide, Professor Turner adopts this symbol O. It goes without saying that uniformity of nomenclature is highly desirable.

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BULLETINS

Here there is room for further improvement and uniformity in harmony with the resolution of the international conference at Manchester in 1911. Most American stations that issue bulletins issue them on the prescribed foolscap sheet size. Those that do not would confer a favor on the others by falling in line with the accepted form. But of greater moment is that some, many, do not issue a monthly bulletin at all, in fact some have not even an annual report. The records of such stations are practically lost to the scientific world. The lack of individual bulletins is in a measure made up by the publication in the "Monthly Weather Review" of Washington the monthly records of some twenty American stations a few of which issue monthly bulletins. From unavoidable circumstances such records are two or three months old when received. To publish only annual reports, which means probably fifteen months after a January earthquake, is not fair to the scientific world. They lose very much of their value by being withheld from incorporation in seismological studies and investigations. The annual reports are desirable, but a monthly bulletin is much more so. A few stations have the laudable enterprise of exchanging printed form post cards immediately, giving data of a severe earthquake. Publish, publish, publish at the earliest possible time and make the data available to the world, should be the aim of every station.

INTENSITY SCALE

Personally I am at present more concerned in obtaining reliable seismograms and in their proper interpretation than in an arbitrary intensity scale. I quite agree with Montessus de Ballore and Branner about the unreliability of the personal estimate, and the modification suggested by the latter to the Rossi-Forel scale should answer our purpose for the present. The only scientific scale must be a dynamic one, based upon C. G. S. units.

CENTRAL BUREAU

It was hoped that when seismology obtained a legal status at Washington a new dawn would break. Let us trust that our hopes will yet be realized. The Central Bureau of the International Association did much, accomplished much, yet has not achieved that position that the writer, who has

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on several occasions visited it at Strassburg, expected it to attain in its usefulness to seismologists. Before we get out better tables, before serious geophysical problems involved in seismic records are undertaken, we must have better records and still more, better interpretations of the records. Some of the data are so imperfect at present that it does not seem right to incorporate them in investigations. It is believed that most seismologists, anyway in America, had to grope their way into the subject without any personal aid or assistance or explanation about instrument or seismogram. It is not to be wondered at that the interpreted records lack precision. The distribution of American stations is wide enough to furnish material to deal with world problems in seismology.

My idea of a central bureau at Washington is that it be a clearing house, and intelligence bureau; a bureau to which we can send our seismograms to have them read and interpreted, subsequently to be returned, each with its reading and remarks. Location of epicenters can be more efficiently done at a central bureau than at individual stations. By means of such a bureau there would in a short time result co-ordination that now is enveloped in a distant future. The study of the seismograms from various instruments would disclose defects, and defects discovered presumably lead to defects remedied. It would give new life to each station; each station would feel that it is a unit in the new structure of seismology that is trying to unravel the hidden truths of the surface and interior of our earth, which is after all the most important, to us, of all the heavenly bodies.

To give an idea of the unsatisfactory situation with reference to earthquake records, one need only turn to the interesting compilations found in the Shide "Bulletins." Take at random the one for April and May, 1915. Glancing over it one finds differences between the observed and computed P. similarly for S, based on an epicenter computed by Shide, running to 100^s, to 300^s, to a 1000^s, and even to over 2700^s, that is, more than 45 minutes of time. Surely there is something radically wrong. What's the use of talking about correcting our tables by a few seconds or so, when we still have material like that to deal with? Is it not our first duty to get fairly reliable records?

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The bureau might properly undertake too the testing of instruments before they have been permanently set up, as has been done at Strassburg. Such testing and examinations would give greater confidence to the observer in the performance of his instrument. When we once have reliable data then the field of geophysics may be entered by those who have the necessary mathematical implements to cultivate it, taking up any particular branch of research that appeals to them. But to repeat, we must first have reliable data.

Perhaps my conception of a central bureau at Washington appears like a "pretty big order," but it is worth while if seismology is to have the scientific standing it deserves. The first year or so would undoubtedly have the heaviest drain on the bureau till all or the important stations at least would have their seismograms co-ordinated. The bureau would be expected to publish the earthquake data from the various stations, together with monographs and other matter pertinent to seismology. Such a bureau would be perfectly in line with similar bureaus already established at Washington.

Now a few words about the Pacific, encircled as it is by a seismic girdle and dotted with seismic fields. Many seismologists, I am sure, have longed for a well-equipped seismological station in Hawaii; for well may one say it has "earthquakes to right of it, earthquakes to left of it, earthquakes all around it." An efficient station at Honolulu in charge of a capable scientist and staff could do more in one year than is now done at a half a dozen or more stations. One need but look at a map and note the favorable position of Honolulu for recording the quakes of the East Indies, Japan, the Aleutian Islands, the western coast of North and South America, and of the South Pacific. It is a perfect seismological paradise ready to gather the fruits of recent earthquakes. It is to be hoped that the Pan-Pacific Scientific Conference will take the necessary steps that may or will lead to the establishment of such a station at Honolulu.

To support and enhance the value of such a mid-Pacific station it is desirable that other first class stations, instrumentally anyway, be established around the girdle referred to. The following are suggested: Unalaska, Victoria, San Francisco, or other point in California, Colima, Panama, Callao,

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Santiago or Valparaiso, Samoa, Christchurch, Sydney, Manila and Tokyo. Some of these places are already supplied with seismographs, but not all of the same merit. In this latter lies one of the undesirable conditions. The places mentioned are given more with the idea of distribution than of definite location. It seems to me that if correspondence were opened by officials of the Pan-Pacific Scientific Conference with the authorities of the various places or countries touched upon above, outlining a Pacific earthquake campaign, stating its object, and the important results that may be expected therefrom (yes, practical results and advantages, to use that desolating word "practical" foisted upon us in this utilitarian age), a homogeneous cycle of seismological stations could be established that would then be, with their dependable records, of real service in unraveling the mysteries of the crust and of the interior of the earth. Without being too sanguine, I believe that within two years after an earnest and well-planned scheme is presented the effort will bear ample fruit. The supreme desideratum is reliable records. If seismology is to advance after its recent period of "innocuous desuetude," strenuous efforts must be made towards that end. I should like to see it introduced into the course of study in our universities, where at present it is about as unknown as the hieroglyphs of Egypt.

A small committee should be vested with authority by the Conference to compile a scheme for complete installation of a seismological station, suggesting type of instrument (perhaps the photographic Shaw-Milne), time service, monthly bulletins, and other obvious matters; as well as authority to communicate with the Pacific countries soliciting co-operation.

CONCLUSION

In closing these brief remarks, may I express the hope that the Pan-Pacific Scientific Conference will not close its labors without having taken a decided step forward towards furthering investigational seismological work for the Pacific basin, from which science and the world will derive lasting benefit.

DISCUSSION

MR. WOOD: The importance of accuracy in time keeping for earthquake triangulation should be kept in mind. It is especially needed in the location of regional epicenters. A wireless check on time accuracy is desirable. I do not agree with Dr. Klotz concerning the

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extreme necessity of making monthly bulletins as workers must have a certain amount of time for compiling and measurements. There is, however, great need for a central bureau to do the work of critical interpretations of seismology. For problems of triangulation Honolulu is not an ideal central station. It is very distant from some well-known seismic centers and not very well placed for triangulation in specific cases.

MR. ROMBERG: The comments of Dr. Klotz on evaluation of energy by Galitzen's formula are very interesting. It is of great importance to determine the energy actually expended at the recording station, but Galitzin is probably wrong in some of his assumptions leading to the determination of energy at the earthquake source. This determination of energy at the source is a very difficult matter.

MR. WASHINGTON: Great speed in transmission of records to other workers is not necessary and extremely prompt publication of results may lead to excessive publication of error. An elaborate central bureau might reduce the directors of individual seismological stations to mere underlings of the central station.

MR. JAGGAR: This would be true if existing seismological stations were special observatories of distant earthquakes, but they are mostly accessory to astronomical, geodetic or geological institutions. If a central bureau measured seismograms, coordinated the work, and produced results for the other stations to use, great service would be rendered to science, as well as to those stations.

MR. WASHINGTON: Difficulty would be experienced in getting trained men for the central station.

MR. WOOD: The problem before seismology as it exists today is not the establishment of ideal stations, but, rather to operate efficiently the stations which do exist so as to make the results of some use.

MR. OMORI: Attention should be given to the problem of small local earthquakes and frequent earthquakes which must necessarily have local centers of registration, as the area affected by them is very small. The only sure way of determining the direction of the motion is by studying the first departure of the stile of the seismograph at the beginning of the preliminary waves.

MR. JAGGAR: Is it possible to determine the depths of the local earthquake foci?

MR. OMORI: I believe the angle of emergence could be determined, but there would be distortion of the path of the waves owing to the nature of rocks. This method does not necessarily determine the depth with any accuracy.

MR. JAGGAR: How many stations are really necessary for work in teleseismic registration?

MR. WOOD: The National Research Council recommends that nine stations of the first class be established. A plan for a group of stations has been drawn up to meet the needs of the Southwestern United States and Southern California, which has met the approval of the Division of Geology and Geography of the Research Council.

MR. HOVEY: It is desirable to have a central bureau in Washington for the work of the United States. The seismograph in operation at the American Museum of Natural History is a type of third-rate station where the workers cannot be expected to give first attention to the problems of mathematical analysis of seismograms.

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MR. JAGGAR: In plans for Pacific work, regional studies and direct human needs should be accented.

MR. WASHINGTON: A problem for seismological work is the transmissibility of earthquake waves across the foliation and parallel with the foliation of gneisses and schists. Heat and other forms of physical manifestation of energy are transmitted differently in these two directions and the same is probably true of earthquake wave motion.

MR. JAGGAR: During the Costa Rica earthquake of 1910 the isoseismals were crowded in crossing the Cordilleran axis, but moved out evenly and gradually across the coastal plain on the Caribbean side.

MR. HOVEY: Registration at the American Museum, of dynamite blasting in the vicinity was marked in the direction parallel to the foliation.

MR. H. F. REID, PROFESSOR OF GEOLOGY, JOHNS HOPKINS UNIVERSITY (From a letter to the Chairman): So far as seismology is concerned, the Hawaiian islands themselves are only moderately seismic. The shocks there are apparently directly connected with the volcanic activities and the two should be studied in conjunction. There are many regions in the Pacific Ocean where earthquakes are both frequent and violent and they are known in a general way but it would be a great advantage if the ocean as a whole could be studied to determine the exact relations of earthquake centers. This work would have to be done by means of instrumental records. There are seismographs in Chile, Peru, Panama, Central America, Mexico, California, Sitka (Alaska), Japan, Formosa, Philippines, Guam, Sydney (Australia), New Zealand, and Samoa and of course in Honolulu. This makes a pretty good distribution around the Pacific. It would be a great advantage if an instrument could be mounted somewhere in the Aleutian Islands and also on one of the islands of the southern group. I understand the Samoan observations have been kept up during the war and that the observer would like to receive moderate payment for his work during that period. This seems to me reasonable and if it comes within the scope of the Conference I hope that it may be approved and carried out.

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SEISMOLOGY IN AUSTRALIA

By E. F. Pigot, Director, Seismological Observatory, St. Ignatius College, Riverside, Australia, and L. A. Cotton

The earliest registered earthquake in Australia took place on June 22, 1788, and was recorded by Governor Phillip at Sydney Cove. Numerous small shocks have since been recorded, chiefly in southeastern Australia. In very few cases has the intensity of the shocks exceeded degree V on the Rossi-Forel Scale.

An extraordinary number of shocks, for which there appears to be good authority, are stated to have been felt in Tasmania during the three years and nine months from April, 1883, to December, 1886. In fact, no fewer than 2,540 shocks were registered by the Meteorological observers throughout Tasmania during this period. Four of these shocks reached intensity VII on the R. F. scale, but the average intensity was only between degrees III and IV. The greatest shock affected the whole of Tasmania as well as portions of New South Wales and Victoria. This appeared to be of submarine origin.

The most severe earthquakes recorded on the continent itself are those which cccurred at Adelaide in May, 1897, and at Warnambool, in Victoria, in April and July, 1903. The Adelaide shock was also of submarine origin and reached a degree of intensity IX (R. F. scale) near Beachport and Robe. The Warnambool shock of April 6, 1903 reached a degree of intensity VII (R. F. scale).

A great number of small earthquakes have been recorded in South Australia, Victoria, and southeastern New South Wales, but little systematic study has been given to these phenomena. The horizontal pendulums which have been established at Burrinjuck for the purpose of measuring the earth tilt under water load have recorded a number of these small shocks. They are undoubtedly due to local faulting, for which there is also strong physiographic evidence in this district.

There is ample scope for good systematic work for field seismology in the Australian region. The study of seismology in Australia was stimulated by the formation of a committee of the Australian Association for the Advancement of Science

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in 1891. This committee has striven to advance seismological science chiefly along the lines of instrumental research.

The earliest types of seismographs used were the Gray-Milne instrument at Melbourne Observatory, the Ewing instrument at Sydney Observatory, and locally made instruments installed by Mr. Briggs at Launceston, Tasmania. These, however, have long since been discarded, and the installations at present in use are as follows:

Located at	Erected by	Recording since	Type	Component
Perth, W. A.	W. E. Cooke	Oct. 1, 1900	Milne	EW.
Melbourne	P. Paracchi	Apr. 19, 1902	"	EW.
Sydney (Obs.)	H. C. Russell	May, 1906	"	EW.
Adelaide	G. F. Dodwell	July (?), 1909	"	EW.
Riverview	E. F. Pigot	Mar., 1909	Wiechert	(1) NS, EW.
"	"	Apr., 1909	"	(2) Vert.
"	"	June, 1910	Mainka	(3) NS, EW.

The Riverside Observatory is of course by far the best equipped observatory in Australia, and quite recently some additions have been made to the instrumental equipment in the shape of a complete set (3 components) of aperiodic Galitzin seismographs, with 3 recording cylinders. It is anticipated that the new instruments will be in full operation in the course of the next few months. The earthquakes recorded at the Riverview Station since 1913 are: 1913, 175; 1914, 134; 1915, 129; 1916, 218; 1917, 289; 1918, 265; 1919, 201; 1920 (to Dec. 13th), 228.

Full details of nearly all these seismograms have been mailed to the most important seismic stations of the world, and special bulletins have been published from time to time in the case of exceptionally severe earthquakes.

The most important extension of seismological research required in Australia would appear to be the establishment of a first class station in Papua, and an active development of field seismology.

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EARTHQUAKE FAULTS IN AUSTRALIA

By C. A. Sussmilch

In eastern Australia earthquakes are both few in number and unimportant in their intensity and effects. Such as do occur appear to be definitely connected with faults which were developed during the uplift of the tableland belt of eastern Australia at the close of the Tertiary Period (Kosciusko Uplift). At this time a belt of tablelands 100 to 200 miles in width was uplifted along the whole eastern margin of Australia, to altitudes varying from 1,000 to 6,000 feet. This epirogenic uplift was accompanied by extensive normal faulting, most of the faults being parallel to the main axis of uplift (north and south); some of these faults have a throw of at least 2000 feet. The uplift was most pronounced in the south-east corner of New South Wales. Here the faults are more numerous and of greater throw than in most other parts of the tableland belt, and it is in this region that the recorded earthquake shocks are much more numerous than in any other part of the state.

Professor L. A. Cotton has recently worked out the details of an earthquake which affected Sydney and the Blue Mountain area in 1920 and shows conclusively that it was associated with a line of Tertiary faulting (the Kurrajong Fault).

In south Australia earthquake shocks are more frequent in and about Spencer's Gulf, on the south coast, than in most other parts of Australia, and this is also a region of extensive late Tertiary faulting. Spencer's Gulf itself is a submerged rift-valley, to the east of which lie the fault blocks of the Mount Lofty ranges. Here also there seems to be no question that the earthquakes are definitely connected with the late Tertiary faults.

In no case has any actual displacement or faults in Australia been seen at the time of earthquake shocks, but in view of the mildness of such shocks as we have, this was hardly to be expected.

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HAWAIIAN EARTHQUAKES

By T. A. Jaggar, Jr.

The substance of this paper appears in Bulletin of the Seismological Society of America, vol. 10, No. 4, pp. 249-264, December 1920.

SEISMICAL PHENOMENA AT SAMOA

By G. Angenheister, Director of Samoan Observatory, Apia, Samoa

Outline of an illustrated paper transmitted by the author, whose attendance at the Conference was prevented by passport regulations.

A. Movement of the earth's crust not due to earthquakes.

- I. Microseisms on calm and stormy days (pulsations).
- II. Tilting of the ground due to tidal load of Apia.
  1. Harbor seiches
  2. Earthquake tidal waves 1.5×10^{10} C.g.s.
  3. Ocean tides

  The rigidity of the earth's crust derived from tilting of ground by tidal loads increases with increasing wave-length of the passing waves:

  Rigidity derived from

  1. Harbor seiches 1.4×10^{10} C.g.s.
  2. Earthquake tidal waves 1.5×10^{10} C.g.s.
  3. Ocean tides 2.0×10^{10} C.g.s.

  The greater the wave length the deeper are the layers of the earth's crust which are affected by the loading.

B. Earthquakes

- I. Different types
  1. Local earthquake, deep-lying focus
     Local earthquake, more superficial focus
  2. Distant earthquake (2400 kilometers)
  3. Far distant earthquake (8000 kilometers)
- II. Earthquake frequency
  - a. Day of high earthquake frequency
  - b. A world-earthquake and i s aftershocks
  - c. Earthquake frequency and moon-phases

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C. Earthquakes and the surface and interior of the earth
   I. Earthquakes and the form and structure of the earth's surface
      1. Earthquake epicenters near the Tongan deep, all on the western side
      2. Earthquakes and earthquake-tidal waves in the Pacific. Mean depth of the Pacific derived from the velocity of earthquake-tidal waves
   II. Thickness of the upper earthshell
      1. The splitting of the first preliminary tremor into two parts (P emersio and P impetus) between 200 and 700 kilometers distance of hypocenter suggests a discontinuity in the earthcrust at a depth of 50 kilometers (most probably fluid lava) and a sudden change in velocity of propagation.
      2. The very constant period of main-waves depends most probably only on the thickness and elasticity of the upper shell. A thickness of about 35 kilometers is derived from the velocity of propagation and the period of the main waves. There are indications that the period of the main waves passing through continents and under oceans differs in length; this would suggest a different thickness of the upper shell below oceans and continents.
   III. The structure of the earth's interior
      The time of the three largest earthquakes from the Tongan Deep shows not much difference from time curves of continental earthquakes. With the exception of the upper shell (50 kilometers) there seems to be no marked difference for deeper lying shells under continents and oceans in regard to the rate of propagation of longitudinal waves, and so to elasticity and density of the material. It was possible to follow the first preliminary tremor to a distance of 160 degrees from the hypocenter.

D. Tides of the ocean, underground water, earthcrust, atmosphere, and magnetic horizontal intensity in Samoa.
   I. The tides of the crust follow the tides of the ocean very closely without difference in phase. The amplitude of deflection of the plumb line being .15″ is almost entirely caused by the tilting of the ground due to

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tidal loads of the ocean. The pendulum is 10 m. distant from the highwater mark.

II. Comparison of atmospheric tides from different observatories shows clearly an increase of amplitude with decreasing latitude.

III. The change of pressure per hour (rate of change of pressure) in the atmospheric tide at Samoa corresponds closely in phase with the tide in terrestrial magnetism at Samoa. This means the maximum of horizontal tidal movement in the upper atmosphere corresponds with the maximum of disturbing force in terrestrial magnetism.

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EARTHQUAKES AND VOLCANOES OF THE PHILIPPINE ISLANDS

By Miguel S. Maso

EARTHQUAKES

Systematic study and statistics of earthquakes in the Philippine Islands began in the year 1880 when violent shocks caused great damage to the city of Manila. Such a start must be credited to the Jesuit, Rev. Fr. F. Faura, Director of the Manila Observatory, a private institution founded fifteen years before in the Jesuit College, and to the chief of the Bureau of Mines, Mr. J. Centeno.

Before that year some few papers had been written by Mr. J. Centeno and by explorers, visiting the country. In 1881, the military architect, Mr. Mariano Cortes Aguillo prepared and published a pamphlet containing general directions and rules for the construction of buildings as earthquake-proof as possible; his directions were adopted by the Spanish Government and enforced as official ordinances to be observed by the builders and contractors.

Earthquake records began to be published regularly by the Manila Observatory in 1890. This institution had received full recognition of its usefulness and necessity from the Spanish Government in 1884, and since then was considered as an official bureau and supported by public funds. A general catalog, as complete as possible, of Philippine earthquakes, illustrated with numerous maps of seismic areas, and descriptions of instruments and results of seismic observations was published by the author of this report in 1895 under the title "La Seismologia en Filipinas." The Manila Observatory was at that time equipped with a Secchi seismoscope, a Gray-Milne seismograph, a Bertelli seismoscope and a Rossi seismoscope. During the period preceding the American occupation the observatory maintained official relations with only fourteen meteoro-seismic stations in the main island of Luzon, but practically all telegraphic operators acted as seismic reporters, or correspondents. For reports from other islands of the archipelago, the observatory depended on private reporters; yet it can be said that from 1880 up to 1898 not a single remarkable earthquake occurred in the Philippines, of

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which the observatory did not receive prompt and accura e reports. During the same period some interesting papers were published by the Manila Observatory and by the Chief of the Bureau of Mines, Mr. E. Abella.

With the American sovereignty came an extension of telegraphic lines to the southern islands of Visayas and Mindanao, and the foundation of the Weather Bureau in the existing Manila Observatory, under the direction of Rev. Jose Algue, S. J.; meteoro-seismic stations were opened throughout the country and the telegraphic reports of earthquakes began to be as complete as could be desired. Many stations were provided with seismoscopes and special printed instructions to make the reports accurate.

Later on, the Central Observatory, or Weather Bureau at Manila, received a Vicentini seismograph, two Omori horizontal pendulums, and a 1000 kgs. Wiechert seismograph. Moreover, there exist at present the Baguio Station (16° 25′N., 120° 36′ E., 4950 feet above sea level), with a Vicentini seismograph and two Omori horizontal pendulums: the Taal Volcano station (14° 7′ N., 121° 04′ E., 20 feet above sea level) with a Vicentini seismograph and an Agemennone seismograph for perceptible earthquakes: the Butuan station in Mindanao (8° 56′ N., 125° 32′ E., 8 feet above sea level) with a Wiechert, 200 kilogram seismograph: the Naval Station at Agana (Guam) 13° 28′ N., 144° 45′ E., 14 feet above the sea level) with a Wiechert, 200 kilogram seismograph. There are also in operation four home-devised seismographs at Camiguin, a volcanic island north of Mindanao; Irosin, close to the active volcano Bulusan, southeastern Luzon; and Tigaon, close to the extinct volcano Isarog and not far from the active volcano Mayon, southeastern Luzon.

The standard time used throughout the islands is that of the 120th east meridian or eight hours east of Greenwich. Every day at 11 A.M. the time is sent by wire to all the observers.

The yearly number of earthquakes felt in the Philippine islands can be seen in Tables 1 and 2 which comprise only the last seventeen years considered as most reliable. Table 1 contains the earthquakes, and Table 2 the seismic disturbances recorded at Manila during the same period.

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The number of violent and destructive earthquakes, VII grade and up, during these years has been 63; the years 1913, 1915, 1917 and 1919 figuring with seven, six, seven, and eight respectively.

TABLE 1. EARTHQUAKES IN THE PHILIPPINE ISLANDS, 1903-1919

Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	T't'l
1903	12	5	8	8	15	13	9	24	10	12	17	8	141
1904	22	10	10	9	6	8	11	5	11	15	4	6	117
1905	14	8	12	11	10	8	12	10	11	16	8	12	132
1906	13	6	5	12	6	11	9	9	9	11	5	7	103
1907	13	7	10	14	22	17	14	16	5	5	15	7	145
1908	17	6	11	6	13	9	5	11	8	10	15	11	122
1909	11	8	9	13	12	5	12	12	14	10	5	9	120
1910	13	13	14	12	23	18	22	8	12	21	23	17	196
1911	12	14	21	13	17	15	13	27	29	19	16	18	214
1912	14	21	28	16	15	18	22	15	15	14	12	12	202
1913	9	18	25	5	15	15	12	13	11	7	8	10	148
1914	15	17	12	10	5	11	14	12	13	10	13	14	146
1915	11	14	12	11	14	15	18	12	12	14	12	14	159
1916	13	15	12	7	8	8	15	18	20	15	7	5	143
1917	6	11	13	12	11	11	7	12	12	17	21	13	146
1918	12	17	8	12	19	11	16	14	11	13	20	14	167
1919	12	11	16	8	8	16	17	15	13	11	11	13	151

TABLE 2. SEISMIC DISTURBANCES AT MANILA, 1903-1919

Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	T't'l
1903	21	20	13	15	16	6	16	16	8	13	9	14	167
1904	15	19	11	19	17	35	25	18	16	26	18	18	237
1905	30	23	18	22	22	29	28	9	24	26	14	29	274
1906	30	17	22	27	13	35	11	14	14	86	21	26	316
1907	16	12	21	32	35	17	19	15	21	14	43	14	259
1908	16	14	23	15	20	12	14	15	9	108	25	24	295
1909	21	24	24	22	25	14	26	15	20	6	13	7	217
1910	20	17	20	17	17	21	19	11	12	18	15	29	216
1911	16	19	30	22	24	30	31	35	30	28	28	22	315
1912	27	16	30	24	23	35	27	35	20	20	31	34	322
1913	44	20	37	61	42	25	22	41	36	24	13	6	371
1914	22	35	30	48	25	23	24	20	22	26	32	22	329
1915	27	19	21	32	38	33	28	28	30	24	27	31	338
1916	37	46	43	38	37	28	31	28	31	39	22	17	397
1917	31	27	27	35	47	34	39	33	27	43	38	25	406
1918	62	35	32	30	22	37	64	68	45	34	48	53	530
1919	37	31	42	44	47	45	42	23	48	20	24	17	420

A special catalog of all the violent and destructive earthquakes of which any record could be found was published in 1910.[1]

Many interesting papers prepared by the author dealing with earthquakes and the most active seismic centers of the archipelago can be consulted in the file of the monthly

[1] Maso, Rev. Miguel S. Catalog of violent and destructive earthquakes felt in the Philippines 1599-1909. Manila, 1910.

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"Bulletin of the Philippine Weather Bureau." Specially recommended is a paper on the "relation of seismic disturbances in the Philippines to the geologic structure".[2] Likewise attention is called to the work of the eminent seismologist Montessus de Ballore, for the knowledge of Philippine earthquakes.

Plans for the future are to place seismographs in other seismic regions. Much difficulty has been experienced in keeping in good shape delicate seismographs in so damp a country and to find careful observers to take the constant minute pains required by such instruments. Among the regions which deserve special survey is the Agusan Valley, east Mindanao, a structural trough running nearly without interruption from Butuan Bay to the Davao Gulf and parallel to the great "Philippine Deep" of the Pacific Ocean, the largest and deepest so far known. This valley has been always the seat of frequent shocks; a Wiechert seismograph placed at Butuan near to its north end records since 1915 an average of ninety seismic disturbances per month, the greatest percentage of them having their origin in the "Philippine Deep."

VOLCANOES

There exist at present in the Philippine archipelago, seven volcanoes which are or have been recently active. These are: the Kalayan volcano, in the Babuyanes islands, off northern Luzon; Taal volcano, southern Luzon; Mayon and Bulusan volcanoes, southeastern Luzon; Canlaon volcano, northern Negros island; Camiguin volcano, Camiguin island, off northern Mindanao; Ragang volcano, northern Mindanao, and Apo volcano, southeastern Mindanao. Nearly all of these volcanoes represent a distinct volcanic system or region where exist many other extinct cones and craters. In the "Census of the Philippine Islands, Washington, 1904," we included a general report on volcanoes and seismic centers.

So far only a few of them have been the object of geological surveys. Taal volcano was studied by J. Centeno in 1885. On the Mayon volcano Mr. Abella published a long report in the "Boletin Geologico de Espana." Reports on the sulphuric and thermal vents of the old volcano Makiling, southern Luzon, and the sulphur banks of the Biliran island,

[2] Maso, Miguel S. and Smith, Warren D. Philippine Jour. Sci. vol. 8, no. 4, August, 1913.

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north of Leyte, were also published by the same author. Geological data of the principal Philippine volcanoes can also be found in the works of foreign naturalists who visited the country, for instance, Von Richthofen, Carl Semper, Oebbecke, K. Martin, Jagor, Roth, R. von Drasche, and J. Montano. In the early days of the American domination, G. Becker made a more exhaustive and general report about Philippine volcanoes.[3]

A number of more recent studies and physiographical descriptions can be found in the "Philippine Journal of Science," by Dr. Warren Smith and other geologists (vols. 5, 6, 7, and 8, sec. A). The eruptions of the Mayon volcano were catalogued and described in 1898 by Rev. J. Coronas, S. J., of the Weather Bureau in reporting the great eruption of 1897.

The Taal volcano, because of its nearness to Manila and by reason of its last deadly eruption in 1911, has received special attention. Comparative studies of the composition of its ejected sandy materials and ashes and of its fumes, waters and gases and the appearance of plant life on the new volcanic deposits after the last eruption, were published in the "Journal of Science." Statistics and particulars of its former eruptions were published by us shortly after the last eruption of 1911. A second paper dealing with the premonitory signs given by Philippine volcanoes, and with some mud and gravel floods or avalanches occurring in the Mayon and Banahao volcanoes may be found in the monthly bulletin of the Weather Bureau. Two complete geological surveys, one of the volcanic region of southwestern Luzon and the other of southeastern Luzon made by J. G. Adams and W. E. Pratt of the Bureau of Mines, are so far the most reliable studies of the Teal and Mayon volcanic systems. The southwestern volcanic region of Luzon abounds in crater lakes, some of them a most beautiful feature of the country.

At present the volcanoes under more constant observation are Taal and Bulusan. After the last eruption of the Tall volcano in 1911, it was decided to build a volcano station as near as possible to its main crater. But as the Taal craters are located in an island built up by eruptions of an explosive character, consequently consisting of movable and soft materials, located in the middle of a broad lake, the proposed

[3] Becker, G., Report on the Geology of the Philippine Islands. 21st Ann. Rept., U. S. Geol. Survey, Washington, 1901.

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station had to be placed on the nearest and most accessible shore of the lake, where hard old banks of tuff offered a stable base. Outcrops of solid lava of basalt nature are found at great distances from the volcano. The primary object in the mind of the Director of the Weather Bureau in establishing and operating such a station was to watch the changes in the activity and interior strain of the volcano; so his first care was to set up a very sensitive seismograph of the Vicentini type, to record micro-tremors. A motor-launch was also provided in order to facilitate regular visits of the observers to the crater, and occasional visits of tourists and scientists. It was also intended by the Government to warn the people living around the shore of the lake in case of an impending eruption. A continuous observation of the changes of level in the lake was also started, but it was found that frequent changes due to copious downpours of rain in a lake rather small and with a very narrow outlet interfered, and prevented the collection of reliable data; these observations had to be given up definitely by the extraordinary quick filling and extending out of the shore near the station.

At present any analysis of the gases of the main vent is nearly impossible: as a consequence of the last eruption the entire bottom of the crater was converted into a deep pool by the waters of the surrounding lake filtering through the soft and porous material of the island volcano; this great body of water seems to act as a powerful condenser of the heat and gases issuing from below: so much so that only some small vents are seen on the nearly vertical walls of the crater.

In fact the last eruption, which consisted practically of one tremendous explosion or blast, was due probably to obstruction and resulted in the clearing of the materials which during nearly a century had been eroded from the walls and carried down by the heavy tropical rains reducing more and more the vents and at last nearly oblitering them. A case which shows what can be feared from a volcano, the vents of which are reduced day by day, either by newly ejected and hardened lava or by solid materials accumulated at the mouth of the main vent or chimney.

Our attention was also turned during the last two years towards Bulusan volcano, which after having been dormant for centuries awakened in October, 1918. The previous year had seen some few small explosive eruptions throwing out

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exclusively the old material that filled the chimney, but in 1918 it began to pour out pasty lava, which formed a current of rough and broken stones within the old large crater, and occasionally poured down a ravine, which seemingly had been opened through the southern wall of the crater as an outlet of the rain water collected in it. Such pourings of lava were very frequent. During the day they resembled black, steaming stones, detonating and breaking into fragments in their fall along the ravine: at night they appeared red hot and sparkling. At long intervals, a current of supposedly more fluid lava rushed down the ravine; during the day it resembled a foaming and steaming current of grayish mud, which ended in a gray cloud of dust covering the ravine and its borders; the dust cloud darkened as it was rising, some streaks of it remaining high up among the cumulus clouds for many hours after each pouring. So far, the results of the activity of this volcano have been falls of sandy ashes on the plantations and towns around the mountain with very little or no damage. Nevertheless, to appease the people of the near-by towns, who feared greater eruptions in the future, scientists of the Weather Bureau and of the Bureau of Science were sent to the place to examine the conditions. The first step was to place a sensitive seismograph as near as possible to the volcano in order to detect microseismic movements revealing residual interior strain. The instrument showed that there were not such movements, excepting the expected shock produced by each explosive eruption: consequently the opinion was that the volcano had only normal and easy discharges which would prevent accumulation of new great energy. An impending great eruption was considered as improbable: in fact the occurrences of nearly two years of activity have proved the accuracy of this conclusion.

During the last five years two other very little known volcanoes had explosive eruptions. The first, Ragang volcano is situated in central Mindanao in the Moro country: It belongs to the volcanic region of the widely reported Macaturing Volcano in the Cotabato District. We are indebted to the military authorities of Mindanao for the only reports we posses of its recent activity and location. The second volcano in eruption last year, is the one existing in the island of Kalayan of the Babuyanes group, off the northern coast of Luzon, in a very out of the way situation. We have but

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meager reports given by the captain of a merchant vessel sailing in those waters. Some years ago it was visited by a scientist of the Bureau of Sciences, who found indications of recent explosive eruptions and took some photographs.

A special program will be made for the future closer study of the more active and accessible volcanoes of the Philippines. It is hoped that the Weather Bureau will join hands with the Bureau of Science in paying systematic attention to the activity of such volcanoes.

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SEISMOLOGY AND VOLCANOLOGY IN THE DUTCH EAST INDIAN ARCHIPELAGO

By S. W. Visser, Acting Director, Royal Magnetical and Meteorological Observatory of Batavia, Java

The Royal Magnetical and Meteorological Observatory at Batavia has been during many years the leading organ for the gathering of information about the volcanic seismic phenomena in the archipelago.

Yearly publications of seismic and volcanic happenings have appeared since 1863 in the "Natuurkundig Tijdschrift voor Nederlandsch Indië" published by the Koninklijke Natuurkundige Vereeniging.

A monthly bulletin of microseismic recording at Batavia has been published since 1909 by the Observatory. Since Aug. 1911 this bulletin has contained also the records of the seismograph at Malabar, western Java.

Important work has been done by the Department of Mines both on earthquakes and volcanoes. Investigations on these subjects have been published in the "Jaarboek van het Mijnwezen in Nederlandsch Oost Indië."

The Military Topographical Department has mapped out a large number of volcanoes and craters. (See "Jaarverslag van den Topografischen Dienst in Nederlandsch Indië.")

In order to obtain cooperation of the departments mentioned above, the observation of volcanoes is to be reorganized. The intention is to organize official and voluntary observers. Reports on volcanic and seismic action will be sent as soon as possible to the observatory, that will cooperate with the mining department in taking the necessary measures. Instruments will be established on the slopes of suspected volcanoes. It does not seem desirable to establish permanent volcano observatories as an ambulatory observatory in these territories may do better work.

The study of epicentra of earthquakes in the archipelago has started with a research about western Java earthquakes. See S. W. Visser, Aardbevingen in en om West-Java, Natuurk. Tijdschr. van Ned.-Indië 79, pag 181-201, 1919.)

An investigation about earthquakes in the archipelago will soon be published in English by the observatory at Batavia.

Leveling and triangulation is done carefully by the military Topographical Service.

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EARTHQUAKE AND VOLCANO INVESTIGATIONS OF THE UNITED STATES WEATHER BUREAU

By C. F. Marvin, Chief of Bureau, Washington, D. C.

(Presented at request of the Committee on Program.)

The United States Weather Bureau cordially endorses the resolutions on seismology and volcanology of the First Pan-Pacific Scientific Conference. The limitations of the work of the Bureau in these fields at present under the allotments granted by the Congress of the United States restrict it to the collection and publication in the Monthly Weather Review, of reports of American earthquakes and instrumental data from seismograph stations; the maintenance of seismograph stations at Washington, D. C., Northfield, Vt., and Chicago, Ill., and the maintenance of the Hawaiian Volcano Observatory and its publications.

It is the purpose of the Weather Bureau to expand these activities eventually as funds become available. A volcano station near Lassen Peak, California, and another on or near the Alaskan Peninsula are desirable extensions in American territory of the volcanological observation begun in Hawaii and that under the Philippine Weather Bureau.

In matters of publication the United States Weather Bureau is prepared to go as far as its funds will permit in meeting the requirements of resolutions of the Conference, numbers 3, 5 and 8, dealing with publication respectively of information, statistics, and educational matter bearing on earthquakes, volcanic eruptions and tidal waves.

With reference to resolution 6, recommending the establishment of a central bureau for dissemination of volcano and earthquake information for the Pacific, the offices of the United States Weather Bureau in Hawaii is peculiarly adapted to this purpose, and if it should be the sense of future conferences that this work would best be entrusted to a single government, the Weather Bureau would be hospitable to the proposal to bring this matter before the Congress of the United States.

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VOLCANIC TREMORS AND VOLCANIC EARTHQUAKES

By Fusakichi Omori

(Abstract from stenographic notes.)

At Asama Volcano earthquakes occur near the mountain whether explosions are in progress or not. Earthquakes occasioned by explosion are ordinarily very small. There are sometimes surface explosions in the crater which will make a very small record at a distance two kilometers away and yet will be registered on the tromometer in Tokyo. Volcanic earthquakes entirely without explosions are much stronger than the explosive ones. Some explosions are loud and make detonation. Others are soft puffs of gas. The seismogram recorded at the time of these soft explosions indicates a larger movement of the ground than when the loud detonations take place. The same phenomenon was observed at Sakurajima. In these volcanic earthquakes, the motion is smooth and slow if accompanied by explosion. The first movement of the ground is toward the volcano and the second outward. A volcanic earthquake accompanied by explosion shows much more rapid vibration. The volcanic tremors are quicker in period than the earthquakes, an each volcano has a habit of its own, tremors which appear at times to be precursory of larger events— thus, Unzen, Oshima, and Asama has each its own distinctive habit. In 1910, the outbreak of Usu was preceded by preliminary shocks. In 1902 a policeman had attended a lecture by me at Torishima wherein he had learned about premonitory shocks; this policeman chanced to be at Usu when the earthquakes began, prior to the eruption, and it was owing to his influence that the people were ordered away from the dangerous places. In the case of Sakurajima there were forewarnings of the coming disaster and an outbreak of the neighboring Kirishima and earthquake disturbances all over that province.

Comment by Mr. Wood: There is a type of tremor registered in Hawaii which is harmonic in quality and slower than the spasmodic type mentioned by Dr. Omori. The latter also occurs in Hawaii and resembles rather a series of small earthquakes. A paper by Galitzin, written shortly before his death, discusses the record of a magazine explosion 15 kilometers

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from the instruments which recorded and registered it by means of an instrument wherein a piezo-electric recording device was used. Similar devices have been much used during the war in connection with artillery.

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PAPERS ON METEOROLOGY

SURVEY OF METEOROLOGICAL PROBLEMS OF THE PACIFIC

By Lawrence H. Daingerfield

The Pacific Ocean embraces an area of about 55,000,000 square miles, equivalent to the entire land surface of the globe, and presents to the meteorologist, partly by reason of this vast extent, many features of great interest and importance. In regard to some of these we are already more or less well informed but of others our knowledge is very meager, and many important questions concerning them remain to be answered.

The coördinated efforts of the several nations, whose lands lie within or about the far-reaching borders of the Pacific, are essential to the proper study of these features and the associated physical problems. What appear to be the chief features of Pacific Ocean meteorology calling for study at the present time are presented briefly below, the object being to establish a basis for systematic investigation in the future. It is recognized, of course, that any plan made now, must necessarily be subject to modification.

The survey may be presented in the form of a series of questions:

1. What is the normal distribution of atmospheric pressure over the Pacific Ocean and its adjacent land areas?

2. What is the normal seasonal distribution of pressure?

3. What regions are under permanent high pressure? What under permanent low pressure?

4. What are the regions occupied by high or by low pressure areas, in which pressure conditions vary, or indeed are reversed, with the change of season?

5. Where do typhoons originate? What is their fundamental cause?

6. What are the normal tracks of typhoons relative to place of origin and season?

7. Do typhoons ultimately, say when they enter the region of the Aleutian Islands, become normal extra-tropical cyclones?

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8. Are the "Kona storms" of the Hawaiian archipelago a result of extra-tropical cyclones?

9. If so, what are the circumstances of pressure distribution in the regions of the North Pacific high pressure area and the Aleutian low pressure area which combine to cause them?

10. What are the relations between the prevailing distribution of air pressure over the Pacific and the character of the weather in the Pacific area, such as hot or cold periods, wet or dry, extending at times over months, seasons or even years?

11. Similarly, what are the relations as affecting the weather of the adjacent land areas?

12. What are the interrelations between surface winds and ocean currents?

13. What are the relations between surface water temperatures of the Pacific and air temperatures and, consequently, the positions of "centers of action" and their shifts over that ocean and over adjacent land areas?

14. At what average elevations are the so-called anti-trade winds found from place to place along the tropics?

15. What are the diurnal, monthly and annual variations in anti-trade wind elevations?

16. What are the normal velocities of the anti-trades and the departures therefrom?

17. What are the relations, if any, that exist between volcanic and seismic activity and weather changes?

18. What new facts, if any, can be established with regard to fog?

19. What steps should be taken to increase the practical application of meteorological knowledge?

20. What are the more special meteorological problems of Pan-Pacific countries?

As has been stated, some of the features of Pacific Ocean meteorology are already more or less well understood. This is true of those appearing under questions Nos. 1-6, inclusive. Additional knowledge in regard to these features can only result from the cooperative activities of the several Pan-Pacific nations.

Question No. 7, as to whether typhoons become extra-tropical cyclones, has not perhaps been satisfactorily answered

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and requires further study of observations from the regions lying between Japan and the Aleutian Islands. The suggestion has been made that in this as well as in other connections fixed or semi-fixed vessel-weather stations should be employed in the less frequented regions to supplement reports from vessels on the established trade routes.

Questions Nos. 8 and 9 are in a fair way to be answered. Results might be hastened by the inauguration of the proposed system of vessel-weather stations, which would make available data from certain untraveled waters.

Questions Nos. 10 and 11 may be answered as a result of the same methods of study but a longer period of time, possibly several or many years, may be required in so doing.

Questions Nos. 12 and 13 have been given general consideration for many years. The making of more widespread observations and of a more specific study of the temperatures of ocean surface water and of the temperatures, pressures and winds in the Pacific region appear to be necessary before No. 13 can be answered.

Questions relating to the anti-trade winds, comprised in Nos. 14, 15 and 16, have been considered only slightly and before they can be answered many pilot and sounding balloon observations will be required, as well as observations from land stations of high elevation along the tropics.

Question No. 17, likewise, has received but slight attention. A long series of meteorological, volcanological and seismological observations throughout the Pan-Pacific region and a comparative study of the same will be required before an answer can be made to this question.

The specific meteorological problems of the several pan-Pacific countries, referred to under the head of Question No. 20, are so varied and complex that their presentation would go beyond the scope of this general survey and therefore no attempt is made to enumerate them. However, without knowing what these problems may be, it is reasonable to assume that under the plan of intimate and hearty cooperation evolved at this Conference the mere suggestion on the part of any one nation of a desire for aid from other member nations will meet with a quick and intelligent response.

If methods of procedure were to be suggested at this time, they would doubtless be based upon such general con-

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cepts as uniform scales and measures, synchronized observations, both on land and sea, standardized codes and signals, the more prompt exchange of reports, including a larger daily exchange; and a more liberal policy with respect to the translation from one language to another of books and papers on meteorological subjects.

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METEOROLOGICAL CENTERS OF ACTION IN THE NORTH PACIFIC OCEAN

By Edward A. Beals

About thirty years ago, Teisserenc de Bort, an eminent French meteorologist, called attention to the low pressure areas over Iceland, and the Bering Sea, as "centers of action" for the generation of storms that visit, respectively, Europe and North America.

Since then considerable study has been given the subject, and it has been ascertained that besides these low pressure areas, the permanent high pressure areas over the Atlantic, Pacific, and Indian oceans, and the winter highs and summer lows over the continents are modifying factors to be investigated when the matter is considered as a whole. Owing to the inaccessibility of many of the regions where observations are required slow progress has been made in investigating these centers of action.

This meeting is a step in the right direction for the speeding up of much needed work, and it is particularly gratifying to meteorologists that a plan for a scientific survey of the Pacific Ocean is contemplated. Two powerful centers of action are located in this ocean between the thickly populated continents of North America and Asia, and they are a promising field for thorough and patient examination.

Professor Hann was probably the first to note that a falling barometer in the Iceland low pressure area produced warmer, and a rising barometer colder weather in central and northwestern Europe. Changes taking place in the Bering Sea low pressure area are generally more pronounced than those in the Iceland low pressure area. Reasoning therefore, from Professor Ham's premise, they should modify the weather in the United States and Canada to a greater extent than is done in Europe by changes taking place in the Iceland low pressure area.

The late Professor Garriott, for many years the supervising forecaster in the United States Weather Bureau, maintained that when the depression over the Bering Sea is abnormally low, the North Pacific high pressure area increases in size, and overlaps the southwestern coast of the United States. This overlapping he stated would cause temperatures below the seasonal average in that section of the country.

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He also stated that the overlapping of the North Pacific high would cause the offshoots from the Bering Sea low to take a more northern route than usual in their progress eastward. As a result of these offshoots passing eastward in a northern latitude, large areas in the United States would come under the influence of southerly winds, and weather milder than the average would be experienced over a wide extent of territory.

Professor Garriott gave as examples of the dominating influence of the center of action over the Bering Sea, the mild months of the winters of 1889-90 and 1905-6, and the cold months of the winters of 1903-4 and 1904-5. The mild months he believed were largely due to an unusual depression in the Bering Sea, which extended over part of western Canada and Alaska, and thereby caused offshoots to move eastward in abnormally high latitudes. The cold winter months of 1903-4 and 1904-5 he ascribed to unusually high pressure over the Bering Sea, which contributed to make British America the seat of an area of high barometer from which cold waves emanated and moved into the United States.

Professor Garriott's conclusions are further confirmed by more recent data. During the winter of 1918-19 the pressure over Bering Sea was unusually low, and the North Pacific high was above normal. The winter that year in the United States as a whole was mild, being the warmest of record in many parts of Montana. In the southern Rocky Mountain, and Plateau regions, however, temperatures averaged below normal, which was due to the overlapping of the North Pacific high in the southwestern portion of the United States.

Again the pressure was remarkably high during January and the forepart of February, 1916, in Alaska and Bering Sea, and the North Pacific high was weaker than usual. During this period the weather was abnormally cold in the Northwestern States, the northern Rocky Mountain region and the Pacific States. Storms from the Pacific Ocean entered the United States at relatively low latitudes; heavy rains occurred in California, and abundant snow fell in the mountains of that State.

Major E. H. Bowie, who at the time of this abnormally cold weather was the supervising forecaster at Washington,

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D. C., foresaw on February 12th, that it was about to break, and issued the following special forecast:

Pressure distribution over Alaska is such as to indicate that the prolonged period of cold weather over the Northwestern States will give way to temperatures above the seasonal average within the next two or three days, and moderate temperatures thereafter during the coming week.

In the Monthly Weather Review for February, Dr. Day, the Chief of the Climatological Division of the United States Weather Bureau, stated: "Warmer weather appeared in the West about the end of the second week and gradually overspread the country to the eastward." Major Bowie's forecast was, therefore, fully verified.

Weather forecasts similar to the above are of great value, as the cold had been intense for fully six weeks over a third of the area of the United States. The information that it was about to become warmer was welcome news to a long-suffering public, who had been under heavy expense for fuel and in many other ways had been subjected to discomfort and extra expense in consequence of the cold weather.

Major Bowie has made a close study of the Aleutian low and the North Pacific high for many years, and he has formulated a number of rules which are of great value in predicting the weather in the United States. The two of perhaps most consequence are:

With high pressure over Alaska, more precipitation than usual occurs in the United States.

Cold waves of more than short duration do not occur when the barometer is low over Alaska, whereas intensely cold weather over the United States east of the Rocky Mountains is generally associated with high barometer over Alaska.

The information we now obtain from these two centers of action is extremely meager, somewhat unreliable, and it has only been available for forecasting purposes since radiotelegraphy became practicable, less than ten years ago.

In 1913 the United States Weather Bureau established stations at St. Paul on the Pribilov islands, and at Kodiak, Alaska. At the same time arrangements were made to have reports from these stations transmitted to San Francisco, and thence to Washington, D. C., by the naval radio service and land lines. Some little while prior to this time weather reports had been transmitted daily from Dutch Harbor by the radio service, and from four stations on the mainland in Alaska by cable controlled by the Army.

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Later two other mainland stations were added to the service, which has been maintained in a fairly satisfactory manner ever since. The only station from which reports are received from within the confines of the North Pacific high is at Honolulu, and this is in the southwest quadrant of the high, and for that reason poorly placed for forecasting purposes.

The North Pacific high pressure area forms where it does: first, because of differences in temperature between the North Pole and the Equator; second, on account of the deflection of the winds due to the rotation of the earth on its axis; and third, because the ocean surface is coldest near the latitude where causes one and two operate to produce the formation of the high. The magnitude of the formation, of course, is primarily due to causes one and two, but cause three undoubtedly affects both its magnitude and position to a greater or less extent.

It is assumed by the San Francisco forecasters that when the summer temperature in that city is above normal, the North Pacific high is weaker than usual, and when the summer temperature is below normal the contrary condition exists.

The cool waters off the coast of Northern California as explained by Dr. McEwen are produced by the upwelling of cold waters, that come from either the north or the south; presumably the south. The prevailing winds at San Francisco are westerly, and San Francisco is close to the ocean, therefore these winds will be warm or cool in accordance with the conditions of the surface water over which they have blown for some distance before reaching San Francisco.

When the North Pacific high is weak, few if any offshoots will move eastward across the North Pacific States, and the pressure will be below normal in the interior of the country west of the Continental Divide. This distribution of pressure will result in prolonged, unsettled weather without much rain, but with more than the usual amount of cloudiness. On the other hand, if the North Pacific high is strong, there will be offshoots from it crossing the North Pacific States with considerable regularity, and the weather will be settled, and sunshiny, with warm days and comfortably cool nights over a large portion of the Pacific slope.

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The true measure of the intensity of the high is the barometric gradient, rather than the height of the barometer, and the gradient is shown by the strength of the winds. By measuring the intensity of the North Atlantic high through the strength of the winds, Gallé has been able to forecast winter temperatures in Central Europe from trade wind data obtained during the preceding summer. He maintains a good forecast of the coming winter can be made in seven times out of eight—a high percentage of accuracy.

If forecasts of this character can be made for Central Europe, there is no reason why similar forecasts cannot be made for the western portion of the United States. We would then, of course, have to use the variations in the strength of the North Pacific trade winds of the preceding summer as a base upon which to form conclusions.

Ocean currents move slowly, and if it is possible to determine the temperature of the waters off the California coast at or near where they are upwelling most strongly, then we should know two or three months beforehand whether or not the ocean currents fed by these waters would be warmer or cooler than usual. It can readily be seen that such information would be of great value. If we knew the water was going to be cooler than usual, we would expect a larger high, and if warmer, a smaller high, with in each case the attending weather characteristics in the western portion of the United States.

I have had charted the monthly barometric readings from three stations on the Aleutian Islands, three on the Alaskan coast, and two in the interior of that province. The record covers a period from September, 1914 to May, 1920, inclusive, excluding the summer months of June, July, and August. This record makes a total of 54 charts available for inspection. It was thought by taking the average barometer for the month, it would be possible to show a connection with the weather in the United States for the same month. Thus if the barometer was unusually high over Alaska and the Aleutian islands, the weather in the United States would be cool and wet, whereas if unusually low, the weather would be dry and warm.

Nothing strikingly new has been obtained from studying these charts, but they confirm in a general way the conclusions of Professor Garriott and Major E. H. Bowie as to the man-

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ner in which the changes from high to low affect the weather in the United States. There are occasional exceptions, which probably would be easily explained if the field of observations covered a larger area.

It should be borne in mind that the Aleutian low is caused by a combination of the effects of the general circulation of the atmosphere and differences in temperature between the water and the mainland. In trying to find out why it is more energetic at one time than at another, the question of temperature should be carefully looked into.

The only temperature record from a station in Siberia that I have been able to obtain, synchronous with similar records from stations in Alaska and Bering Sea, is for the winter of 1906-7 (December, January, and February). The mean temperature of that winter in Irkutsk was zero Fahr. (—18° C.); at Eagle, Alaska, it was —15° Fahr. (—26° C.); and at Dutch Harbor on the island of Unalaska at the southern edge of the Bering Sea it was 33° Fahr. (0.6°C.). This shows a difference in mean temperature of 48° Fahr. (28°C.) between Eagle and Dutch Harbor, and a difference of 33° Fahr. (18° C.) between Irkutsk and Dutch Harbor. These differences are ample to produce the low winter barometer readings over the Bering Sea.

It may be that the activity of the low is increased because the water is warmer, or the land is colder than usual. If it is the water that is warmer, then observations of the temperature of the Japan current near Formosa (Taiwan) would probably give information of value by permitting us to know three or four months beforehand that water warmer than usual was about to reach the Bering Sea. If it is the land that becomes colder, then weather reports from the interior of Siberia and Alaska are necessary, for it may be that a better understanding of the temperature conditions in these two countries will enable predictions to be made of cold spells for several days ahead as is now done in the case of cold waves visiting the United States and Canada. If it is possible to ascertain beforehand that the Aleutian low is about to change its position, or to become either more or less energetic, such information would have a direct bearing on the weather that later will be experienced in the United States and Canada.

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In studying the movements of low or high pressure areas, much more information is needed than a dozen or so reports widely separated from each other, and covering only a portion of the area where activity is greatest. Dr. Bjerkness found when making weather predictions in Norway during the war, he had to increase the number of stations from less than ten to about ninety before getting results worth while. We should have, instead of about ten in the neighborhood of the Aleutian low as at present, no less than a hundred to get satisfactory results.

Over a half a century ago, Lieutenant Maury of the American navy showed what one man could do in the way of classifying knowledge of the sea for the practical benefit of mankind. His work has been an enduring monument for himself, and a shining example for the men of the present navy to follow during the time of peace.

I hope steps will be taken at this Conference to outline a plan of action which will have sufficient weight back of it to cause the governments of the countries bordering on the Pacific Ocean to take decided action in making the necessary surveys, not only for the extension of knowledge regarding meteorology, but also for the extension of knowledge in behalf of the associated sciences represented at this Conference.

KONA STORMS

BY LAWRENCE H. DAINGERFIELD

This article in briefer form but with the addition of charts and tables was published in the Monthly Weather Review for June, 1921.

LOW SUN PHENOMENA IN LUZON

BY WILLARD J. FISHER

Read at the Conference and published in the Philippine Journal of Science, vol. 16, no. 2, 1920.

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THE DEVELOPMENT OF METEOROLOGY IN AUSTRALIA

By GRIFFITH TAYLOR, Associate Professor of Geography, University of Sydney

ORGANIZATION

Sir Thomas Brisbane, while Governor of New South Wales, started the first meteorological record in 1822. In 1832 Dunlop was appointed Imperial Meteorologist. The most emnient of early meteorologists was the German, Neumayer, who was in charge at Melbourne from 1858 to 1863. His compendious memoirs have hardly been equalled since. In most of the states the meteorological work was carried out by the state astronomer until 1906. The Commonwealth Bureau of Meteorology was instituted in 1907 with Mr. H. A. Hunt in charge.

In connection with this bureau the following classes of stations are maintained:

First order: self-recording apparatus; three or more readings a day.

Second order: barometer, four thermometers, rain-gauge; two readings a day.

Third order: usually maximum and minimum thermometers and rain-gauges; one reading a day.

Fourth order: usually rain-gauges only; one reading a day.

The Central Bureau is at Melbourne, and contains a staff of 10 professional officers and 34 clerical officers. The other five State Meteorologists are subordinate to the Commonwealth Meteorologist, but are more or less independent as regards local weather forecasting. Their records, however, are worked up at the central office. There are nearly 6000 observers in Australia, most of which take fourth-order stations and send in monthly rainfall records only. The climatological stations number 220, and consist of second and third-order stations.

Upper air research is being largely extended in connection with military and commercial aviation. Up to the present research has been confined to the central office, though meteorographs have been sent up from other bureaus also. A revolving Kite House is erected on the summit of Stromlo—a ridge some six miles west of the federal capitol. No work

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has yet been carried out here. In 1912-13 a number of *ballon-sondes* were sent up from Melbourne. The records showed that the isothermal layer lies about 10 kilometers above our southern coasts. Interesting results concerning the depth of the sea-breeze layer, and of the eddy winds (highs and lows) were obtained. The conclusions are given in Bulletin 13, by Griffith Taylor.

PUBLICATIONS

Daily weather bulletins, forecasts, rain maps and weather charts are prepared and issued to the public. Storm and flood warnings are also dispatched to the regions endangered.

The "Monthly Report" describes the chief features of Australia's weather from January 1910 to August 1913. It also includes descriptions of notable storms and floods; short essays on current meteorological problems, and summaries of recent research elsewhere. Its publication is temporarily suspended.

"Rainfall Observations"—large memoirs embodying all the rainfall averages, with many graphs and maps—have appeared for Victoria, New South Wales, Queensland and South Australia. Similar publications are being prepared for Western Australia and Tasmania.

A dozen "Research Bulletins" have appeared either in octavo or quarto form. Several by H. A. Hunt deal in a compendious way with the chief climatic data of Australia, for example Nos. 1, 2, 4, 7 and 9. Another series by E. T. Quayle has greatly increased our knowledge of Australian forecasting. Thus No. 3 deals with the origin of flood rains; No. 5 shows how the winter rainfall of southeast Australia can be approximately forecasted; No. 10 deals with the use of cirrus-drift in forecasting; No. 12 describes a graphic method of recording weather data; and No. 15 is an important contribution showing that minimum temperatures when plotted on the chart show where inflows of tropical air (and consequently rains) are likely.

Another series of bulletins by Dr. Griffith Taylor deals with the physiographic and economic aspects of climatology. Bulletins 6 and 8 deal with the evolution of land forms in Eastern Australia, and the control of rainfall and communications. Bulletin 11 is an economic atlas for cattle, sheep and wheat, showing the paramount control by rainfall. Bulle-

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tin 14 is an attempt to correlate climates graphically, and introduces the term "climograph." It contains a discussion of white settlement in the Tropics.

The Bureau in 1913 issued a handbook on "Climate and Weather" by Hunt, Taylor and Quayle.

Several publications on Australian Meteorology have appeared elsewhere. "The Australian Environment," by Dr. Taylor is a large quarto monograph, showing how settlement is controlled by rainfall. It contains the first general study of Australian physiography and the first contour maps of the whole of Australia. (Bureau of Science and Industry, Melbourne, 1918.) A recent paper by E. T. Quayle, Roy. Soc. Victoria, 1920, shows that there is an appreciable effect exerted on the rainfall of Victoria by the irrigation settlements to windward. The Oxford University Press has published a textbook on Australia meteorology by Dr. Taylor. It includes sections on climatology and aviation, and a new theory of the origin of tropical cyclones. In the American Geographical Review a series of articles by Griffith Taylor dealing with the climatic control of evolution has recently appeared.

A fairly complete course of meteorology, and climatology is now included in the Department of Geography at the Sydney University.

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MAPPING THE PACIFIC

ASCERTAINING THE CONFIGURATION OF THE PACIFIC BASIN

By G. W. Littlehales

INTRODUCTION

In the apportionment of contributions in the field of physical oceanography to the discussion of the scientific and practical problems of the Pacific, it has been allotted to me to communicate to the Conference a statement in regard to the fundamental problem of ascertaining the configuration of the basin of that ocean.

The manuscript sheets of the bathymetrical chart prepared by the United States Hydrographic Office, containing all the authentic deep-sea soundings, show the small extent to which the basin has been sounded and the distribution of bottom deposits made known, and prove the inadequacy of existing measurements to define the contours of configuration beyond the continental shoulder. In the North Pacific there is a tract twice as large as the United States which has been crossed by only a single line of soundings about 250 miles apart; and, in different parts of the Pacific, other tracts as large as the continent of Australia remain entirely unfathomed. The majority of soundings are grouped in two lanes running respectively from the United States to Australia and from the Hawaiian islands to the Philippines and Japan. No trustworthy contours of equal depth can be drawn beyond the continental shelf, because, on account of insufficient information, conjecture everywhere arises in attempting to do so. The soundings have generally been spaced too widely apart to admit of conclusions in relation to even the grosser aspects of the orography.

Soundings measured around the boundaries of an oceanic tract do not enable the investigator to interpret the configuration within, since no laws of the distribution of the features of the topography of the bottom can be formulated for his guidance. The features to be depicted remain forever in the unseen world unresponsive to the same degree that is realized in many other branches of geophysics to those resources

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of inductive science by which the accumulation of measurements for the portrayal of details of one part reveal general principles rendering unnecessary the execution of like measurements everywhere else in the other parts.

To define those tracts in the Pacific where no measurements of the depth from the surface to the bottom of the ocean have been made is in itself to offer a program of undertakings for the advancement of knowledge concerning the configuration of the oceanic basin, especially if it be attended with an expression of the intervals that should obtain be ween deep-sea soundings, in order that important mountain systems may not escape detection. Such an undertaking also requires an account of the extent to which the Pacific Ocean has already been sounded and the methods and accuracy with which the accumulated measurements have been made.

HOW THE SEA IS SOUNDED

It was not until long after astronomers had begun to sound out the realms of space and to measure the distances and weigh the masses of the planets that the mysteries of the depths of the ocean began to be revealed. Indeed the ocean remained almost entirely unfathomed until the second half of the nineteenth century. In 1856, Maury writes:

> The most ingenious and beautiful contrivances for deep-sea soundings were resorted to. By exploding heavy charges of powder in the deep sea, when the winds were hushed and all was still, the echo or reverberation from the bottom might, it was held, be heard and depth determined from the rate at which sonud travels through water. But though the explosions took place many feet below the surface, echo was silent and the sea gave out no answer. Ericsson and others constructed deep-sea leads having a column of air in them which, by compression, would show the pressure of the water to which they might be subjected, and therefore the depth. This plan was found to answer well for ordinary purposes, but in the depths of "blue water," where the pressure is equal to several hundred atmospheres, the trial was more than these instruments could stand.

The advent of the microphone has enlarged the limitations of Maury's day by affording an enhanced capability for the detection of sound waves, whose employment has revived the resort to attempts to measure the depth of the ocean by the reflection of sound waves from the bottom. There is included in this presentation a communication on "Depth-Sounding with Listening Devices," by Dr. H. C. Hayes, of the Engineering

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Experiment Station at the United States Naval Academy.[1] The method hitherto successfully practiced in measuring the depths of the sea is to lower a line of rope or wire, under the strain of a weight, from the surface to the bottom. In shoal water, there is cast from the vessel a lead in the form of an elongated truncated cone attached to a hemp cord which has previously been divided into feet or fathoms. The line is allowed to run out through the hands of a man who detects, by the sense of touch, the instant when the lead reaches the bottom, and reads the depth by noting the division of the line which corresponds with the surface of the water. By filling a small cavity in the base of the lead with tallow, a quantity of the sand or gravel or mud upon which the lead strikes becomes imbedded in the tallow and gives an indication of the kind of bottom soil.

The rough surface of a rope presents an obstacle to its free passage through the water, and, therefore, as the depths increase it is necessary to employ heavier weights to carry the line swiftly in a straight course to the bottom, and moreover, stronger rope to bear the increased weight of the lead. In great depths, the size of the rope which is necessary is such as to present considerable surface to the action of submarine currents which carry the line more and more out of the vertical direction in proportion to the duration of the passage of the lead to the bottom, and render the results less and less accurate. Moreover, the weight of the submerged portion of the rope in addition to the weight of the sinker soon becomes so great that a man cannot lift it, and, therefore, cannot assure himself by the sense of touch when the lead has reached the bottom, and as the weight of the submerged part is sufficient at great depths to cause the unwinding of the reel, the line may continue to pass out long after the lead has reached the bottom, and the length thus unwound may bear no relation to the depth to be measured. In addition to these sources of error, there is another arising from the drift of the vessel during the period of several hours which is required to effect a deep sounding with rope.

By the use of wire for sounding great depths all the difficulties and uncertainties which characterize the use of rope are obviated, for the wire, being light in weight and of small cross-

[1] The paper by Dr. Hayes was read by Mr. Littlehales. Information regarding the method described may be obtained from the United States Hydrographic Office.

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section, is not greatly affected by submarine currents, but allows the sinker to pass swiftly to the bottom. While the apparatus for sounding the sea consisted of a weight secured to the end of a hemp cord which was paid out from a simple reel on the deck of a vessel, no reliability could be attained in the measurement of depths, because the cord employed was necessarily so large as to become a controlling element in the weight of the system. But when the project for the Atlantic telegraph cable made it necessary to obtain accurate measurements of the depth of the ocean, Midshipman Brooke, of the United States Navy, took the first great step in providing means for trustworthy deep-sea sounding by inventing an implement in which the sinker, enveloping a tube secured to the sounding line, was detached on striking the bottom and left behind when the tube was drawn up (fig. 1, A).

The modern form of deep-sea sounding cylinder is provided with valves at the upper and lower ends which open upwards, and during the descent allow the water to pass freely through the cylinder so that it experiences a minimum of resistance. On striking the bottom, the slackening of the sounding line causes the trigger to spring back and release the sling that supports the detachable weight. As the lower end of the sounding cylinder sinks into the bottom a specimen of the soil forces itself through the lower valve and lodges in the interior of the cylinder. When the cylinder is hauled up the valves at the top and bottom are closed by their own weight and the pressure of the water, and the specimen is sealed until its arrival at the surface, when it is removed for examination by unscrewing the upper and lower halves of the cylinder.

In the sounding machine used on United States surveying vessels the wire passes outboard from the reeling drum over a guide pulley mounted on a crosshead that works between two upright guide frames (fig. 1, B). Each of the guide frames incloses a spiral spring called an accumulator, which is connected with the guide pulley by means of a rope that passes over a pulley at the top of the guide frame. If the ship is suddenly borne upon the crest of a wave while the sinker is going down, instead of causing a jerking strain upon the sounding line, the stress is communicated to the guide pulley, which moves downward under the additional load and extends the accumulator springs; and, likewise, when the ship suddenly sinks into the

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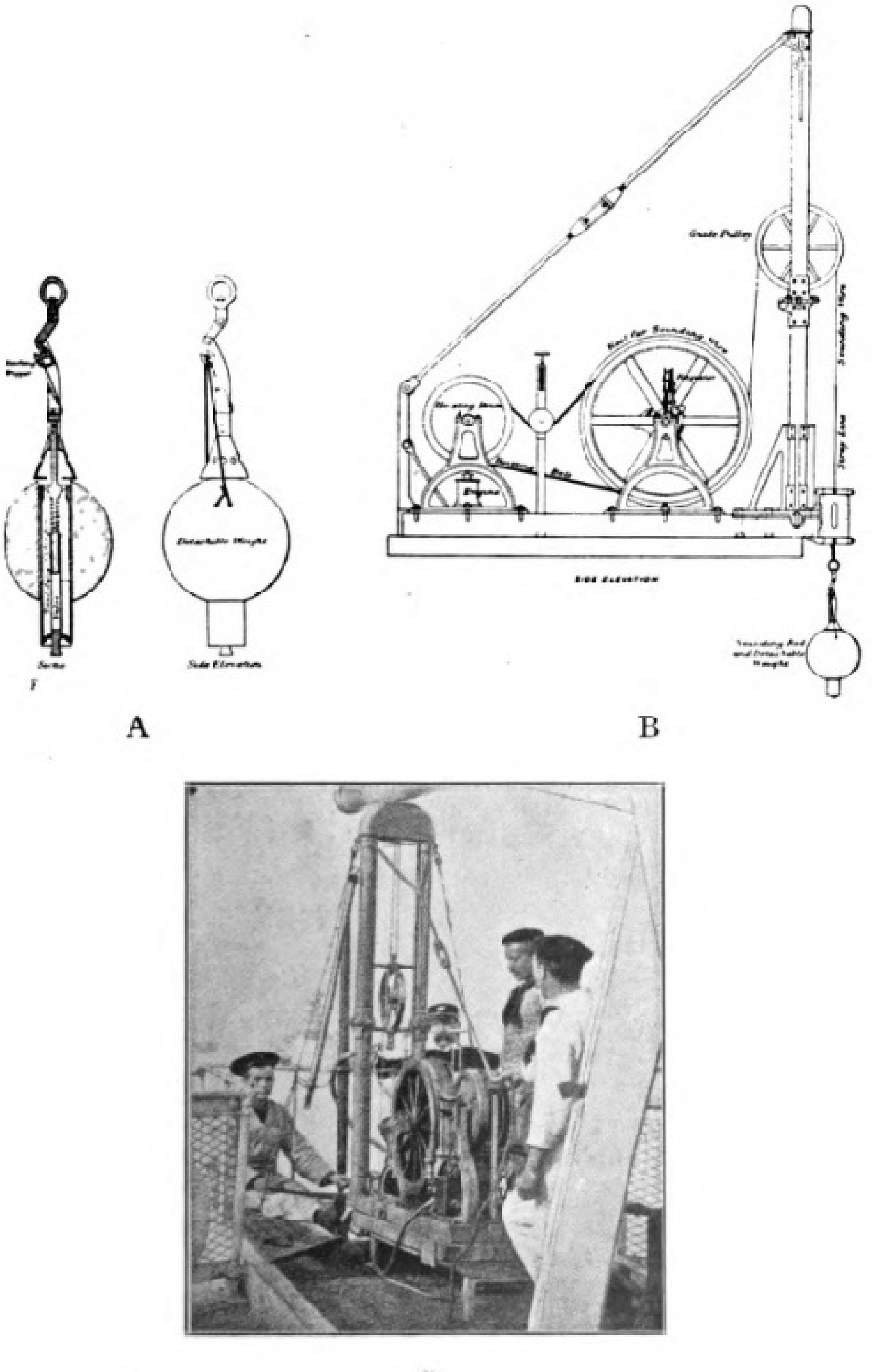


FIGURE 1. Apparatus for deep-sea sounding. (A) modern sounding cylinders; (B) the Sigsbee deep-sea sounding machine; (C) sounding: the sinker going down.

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trough of a wave, the tendency to slacken the sounding line is counteracted by the rise of the guide pulley brought about by the normal tendency of the accumulator springs to contract.

A ship regularly engaged in deep-sea sounding usually has the sounding machine mounted at the after end, and when about to sound is brought to a standstill with the stern to the sea. The stray line with the sounding rod and sinker attached is led over the guide pulley and carefully lowered to the water's edge, the register is set to zero, the deep-sea thermometer is clamped to the sounding line; a seaman is stationed at the friction line which controls the velocity with which the wire is unreeled, another at the brake, and a third on the grating outside to handle the sinker and instruments and to guide the wire as it passes overboard; a machinist is at the hoisting engine, and the recorder takes a position for reading the register (fig. 1, C). When the sinker is let go, the vessel is manoeuvred so as to keep the wire vertical, and the friction line is adjusted so as to allow it to descend from seventy to one hundred fathoms per minute. The instant the sinker strikes bottom, which is unmistakably indicated by the sudden release of the wire from strain, the reel is stopped by the friction line and brake, the recorder notes the number of turns of the reel indicated by the register and determines the depth; the cranks are shipped and sufficient wire is hove in by hand to allow the end of the sounding rod to clear the bottom. Steam is admitted to the cylinder of the hoisting engine, and the wire is reeled in slowly at first, but finally at the rate of 100 to 150 fathoms per minute. The last 10 fathoms are reeled in by hand, then the thermometer is read and the specimen of the bottom soil brought up in the sounding cylinder is examined.

THE EXTENT OF SOUNDING IN THE PACIFIC OCEAN

While it must be remembered that not all the recorded soundings can be laid down on the small scale charts issued by the Hydrographic Office, yet, where none are laid down on the charts, none have ever been measured. And in regions where soundings are represented, if all the recorded soundings could be included instead of the selection which is given where the room does not allow more to be shown, there would yet be too few in general to serve for the delineation of contours of configuration of the bottom of the ocean. Nevertheless, there are some parts of the Pacific where the number and distribution of the

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measurements have proved sufficient to afford an approach toward a fulfillment of this purpose, notably in the lane extending from California to Hawaii, of which a contoured map and profiles are published in United States Senate Executive Document No. 153, 52nd Congress, 1st Session, being the Report of the Results of the Survey for the Purpose of Determining the Practicability of Laying a Telegraphic Cable between the United States and the Hawaiian Islands. Although, as yet, there is little ground upon which to base general conclusions, the diversification found to characterize those areas about which most has been learned prompts a dissent from the former view that the bed of the ocean is a vast level plain.

Coincident with the measurement of depth, other branches of information besides a knowledge of the configuration are subserved. Among these are the nature and distribution of the bottom deposits, and the temperature, salinity, and gas content of the oceanic waters at different depths; and so it has seemed the more pertinent to describe the mechanical operation of taking soundings, because it is by this operation that observations are supplied in relation to many branches of physical oceanography.

INTERVALS BETWEEN DEEP-SEA SOUNDINGS

The intervals between sounding stations must be gauged by the dimensions of the orographical features whose presence is intended to be disclosed. Leaving out of consideration details of topography and confining the attention to features of the greatest prominence, inquiry must be made as to the form and dimensions of the slenderest isolated submarine peak that could be raised from the floor of the ocean to a mountainous height and remain standing under the stresses of its own weight and that of the superincumbent body of water. For, if the spacing of soundings be such as to give indication of the presence of the slenderest form that could stand, then evidence of the presence of any orographical forms that may exist is likely to be afforded. Theoretically, the shape of an isolated submarine peak would be that of a solid of revolution in which the resistance to crushing of any horizontal section is equal to the combined weight of the portion of the formation above that section and of the superincumbent body of water.

Let y denote the radius of any horizontal section and z its distance from the top of the formation. Let K denote the coefficient of resistance to crushing of the material composing

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the formation: w, the weight of a unit of its volume; and w′ the weight of a unit volume of sea water.

Accordingly, $\pi w \int y^2 dz$ = the weight of the formation above any section whose distance from the top is z.
$2\pi w' \int y.z.dy - \pi w' \int y^2 dz$ = the weight of the water upon the formation above any section whose distance from the top is z, assuming the top of the formation to reach to the surface.
$\pi K\ y^2$ = the strength of any section to resist crushing, and

$$\pi w \int y^2 dz + 2\pi w' \int y.z.dy - \pi w' \int y^2 dz = \pi K y^2 \qquad (1)$$

By differentiation, equation (1) becomes

$$\pi w y^2 dz + 2\pi w' y.z.dy - \pi w' y^2.dz = 2\pi K.y.dy \qquad (2)$$

which expresses the condition that the increase of strength of any section in excess of that of the section next above is equal to the sum of the increases of the weight of the formation and the weight of the water upon any section in excess of their combined weight imposed upon the section next above.

Letting S denote the area of any horizontal section whose radius is y; and dS, the differential of S, equation (2) may be written in the following forms:

$$w.S.dz + w'.z.dS - w'S.dz = K.dS$$

$$(w - w')\ S.dz = (K - w'z)\ dS$$

$$\frac{dS}{S} = (w - w')\frac{dz}{K - w'z} = \frac{w - w'}{w'}.\frac{dz}{\frac{K}{w'} - z} \qquad (3)$$

By integration, equation (3) becomes

$$\log S = -\frac{w - w'}{w'}\log\left(\frac{K}{w'} - z\right) + C$$

in which C is the constant of integration.

$$\text{Hence } \log\left(\frac{K}{w'} - z\right) = \frac{w'}{w - w'}C - \frac{w'}{w - w'}\log S$$

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$$\text{or} \quad \frac{K}{w'} - z = \frac{\dfrac{w'}{e^{w} - w'} C}{\dfrac{w'}{e^{w} - w'} \log_e S}$$

In the absence of knowledge of the value that should be assigned to K, the coefficient of resistance to crushing, this equation has been used in the generalized form:

$$A - z = \frac{B}{e^{\left(\frac{w'}{w - w'} \log_e S\right)}} = \frac{B}{e^{\left(\frac{1.03}{2.67 - 1.03} \log_e S\right)}} = \frac{B}{e^{1.446 \log_{10} S}},$$

to find from the observed bathymetrical data in relation to Seine Bank in latitude 33° 50′ N. and longitude 14° 20′ W., Cocos or Keeling Island in latitude 12° 06′ S. and longitude 96° 53′ E., Enderbury Island in latitude 3° 10′ S. and longitude 171° 10′ W., Funafuti Atoll in latitude 8° 25′ S. and longitude 179° 07′ E., Taviuni Bank in latitude 12° 05′ S. and longitude 174° 35′ W., and the shoal near Midway Island in the North Pacific Ocean in latitude 28° 00′ N. and longitude 177° 40′ W., the equation to their average form (fig. 2).

For this purpose the values of z and y, expressed in nautical miles, were inserted in the above equation, and a conditional equation was formed for each pair of coordinates relating to each of the submarine formations. From these conditional questions normal equations were found by the method of least squares, which gave the values of the constants A and B. The resulting equation is

$$1.87 - z = \frac{1.87}{e^{(1.446 \log_{10} \pi y^2)}}.$$

and the corresponding curve, which by revolution around the vertical axis would generate the average form, is shown in the accompanying diagram together with others which have been plotted for purposes of comparison from measured data. This investigation shows that isolated formations occupying

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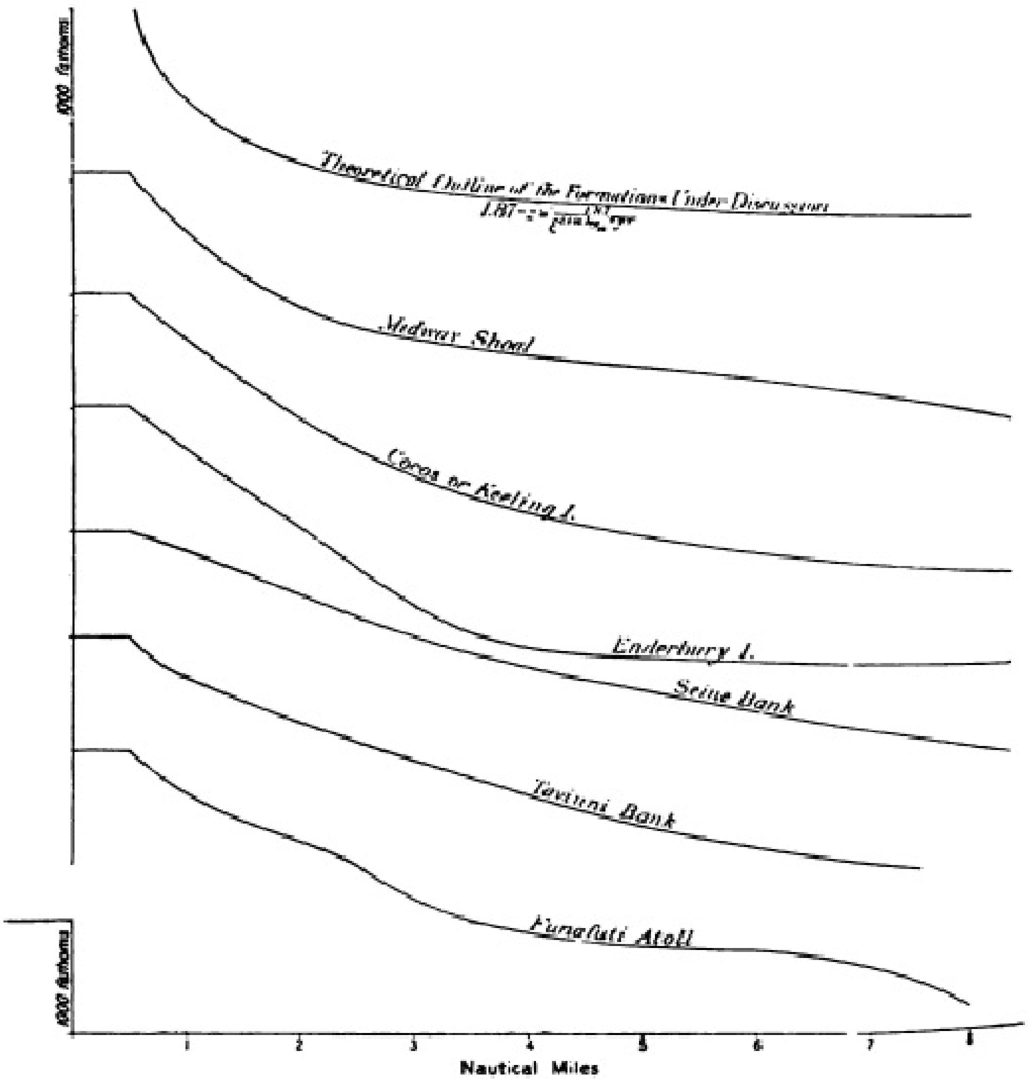


FIGURE 2. Profiles showing relation of intervals of sounding to orographical features.

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comparatively limited areas at the bottom can and do occur in the ocean depths, and we are able to assign at once the maximum interval that should obtain between deep-sea soundings taken in operations directed toward the development of the orography of the bottom of the sea. An interval of eight miles coupled with a differential interval of two miles would serve for general development, and would prove with certainty the existence or absence of any formation rising close to the surface. Of all the possible ways in which an eight-mile interval could lie with reference to a submerged peak, that which would be most advantageous for a prompt discovery of its existence is the condition in which one end of the interval is at the bottom of the slope and the other near the apex, and that which would be least advantageous is the condition in which the interval is bisected by the position of the apex. In the latter case, there would be nearly equal soundings at both ends, but the soundings at the ends of the adjacent two-mile intervals would in all probability give indication of the slopes.

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RESEARCH IN GEODETIC WORK IN THE PACIFIC

By William Bowie

INTRODUCTION

There is no area on the face of the earth where geodetic operations have been more neglected than in the Pacific Ocean, and it is the hope of all geodesists that efforts may be made in the immediate future to carry on certain projects that would furnish much data for a study of the geophysical problems of the earth. The principal lines of geodetic work which should be carried on in the Pacific Ocean are the following:

1. The determination of longitude of many of the important islands.

2. The determination more accurately of the latitudes of the important islands of the Pacific.

3. Triangulation over the larger islands, in order to furnish control for detailed topographic surveys. The triangulation should be supplemented by trigonometric leveling for the determination of the elevations of mountain peaks.

4. The determination of the intensity of the gravity along the continental coasts of the Pacific and on many of the islands.

5. The determination of gravity at sea.

6. The determination of mean sea level by tidal observations at carefully selected places and the connection of these tide stations with firm ground back from the shores of the islands. This connection should be made by precise leveling and the leveling should be repeated at intervals of say 10, 20 or some other number of years in order to test the stability of the outer portion of the earth.

7. The establishment of earth tide stations.

The above-mentioned lines of work will be taken up in detail below.

LONGITUDE

As is well known, the method employed in the past for the accurate determination of longitude of an island has been the cable used in commercial telegraphy. In the oceanic areas it is possible to determine the longitude at only a very small number of points because it is only where cable landings are made that the exchange of time signals over the cable can be accomplished. There are now a number of accurately

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determined longitudes in the Philippine islands and, of course, in Japan and in some of the other groups of islands where cable connection makes this possible and there are many longitude determinations on the continental coasts of the Pacific. (When continental coasts are spoken of, Australia, of course, is considered a continent on account of its extensive area.) There are very few accurate longitudes outside of these groups of islands and on the continental coasts.

We are more fortunate now in having a very easy method of determining the differences in longitude, namely radiotelegraphy. It is a simple matter to receive wireless or radio signals from long distances with apparatus that is not very difficult to transport. All that is needed is to have the local time determined by observations on the stars with an astronomic transit and then to receive by wireless equipment time signals sent from any one of a number of powerful stations. The comparison of the time sent by wireless and the local time gives the difference in time between the two observations and, hence, the longitude becomes known. The determination of local time is a matter of only three or four nights of successful observations. If there is any choice in the selection of time at which such a comparison of work should be taken, that season should be selected when there is most likelihood of having clear weather. The rainy season, of course, would be a very inappropriate time, for the making of local time observations might require months at a station where, under the best conditions, a week at a station would be ample.

It would appear to be desirable that each one of the large islands should have at least one accurately established longitude station and many of the islands of lesser importance should also have their longitudes determined by wireless. There are many small islands, often uninhabited, of no commercial value, and not in the track of vessels, whose longitudes might not be considered of prime importance, at least during the near future. They should have their positions determined in the future with fair accuracy, but this might be done by the ordinary methods of the navigator, using an accurately established longitude station as the point of departure of the vessel making the determination of longitude of the smaller islands.

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LATITUDE

The determination of the latitude of a point on the earth's surface is not dependent on the exchange of time signals and, therefore, it can easily be determined at any place where an astronomic instrument can be set up. One night of observations with a zenith telescope on ten or twelve pairs of stars will give a value for the latitude that is correct within a small fraction of a second of arc. This is ample for any geographic or other scientific purpose.

TRIANGULATION

Many of the islands that are close to others can have their geographic positions, that is latitudes and longitudes, determined by triangulation. This, as is well known, is the method used in any large area for the establishment of horizontal control stations to be used in various classes of surveys and maps. It is essential, of course, in order that triangulation be done among islands that there is one island available that has dimensions great enough for the measurement of a base line. The base line should be at least one-fifth as long as the other two sides of the triangle of which the base line forms the third side. If the base is much shorter than this proportion, the determination of the lengths of the two sides of the triangle would be quite weak and if the triangulation should be extended from those lines for a considerable distance, serious errors might be accumulated in the system. The astronomic longitude and latitude of an initial station would of course have to be determined.

Triangulation has been carried along many of the continental coasts of the Pacific. Japan is completely covered by triangulation and this is, to a great extent, true of the Philippines. Triangulation has also been extended among other groups of islands but not to the extent that is desirable for geographic positions.

In the Hawaiian group some of the islands have been covered by triangulation but more work should be done at an early date for the control of the surveys and maps of the islands. The triangulation should be done in accordance with the standard methods, with accurate base line measurements, in order that whatever is accomplished would not have to be duplicated in the future. The difference in cost be-

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tween triangulation of a high order of accuracy and that of a low one is very small. An hour's more observation and a more refined instrument used at a station will make the work more accurate with practically no additional cost.

Triangulation has a very practicable value in furnishing points which can be used not only for the control of maps but for cadastral surveys, that is, for the purpose of furnishing the coördinates, either rectangular or spherical, for the turning points in the boundaries of private and public property. When such points are connected with the triangulation the boundary may be considered as being perpetuated; that is, all the monuments that might be set could be destroyed and yet the positions occupied by them could be easily recovered by carrying a triangulation from undisturbed points to the area for which the boundary points are to be recovered.

Anyone who has had experience with accurately controlled maps and those on which there is no control understands the great advantage of having the map that is true to scale and in the proper geographic position.

Another advantage of having a triangulation of a group of islands all connected, over the determination of the latitude and longitude of separate islands by astronomic means, is that the distances between the islands can be accurately determined by triangulation, while with astronomic observations, we have the troublesome deflection of the vertical or the station error which, between any two stations, might be as much as a large fraction of a kilometer.

We have one very notable case of local deflection of the vertical on the island of Porto Rico. There are well established astronomic stations at San Juan, on the northern shore, and at Ponce on the southern shore of that island. These two astronomic stations were connected by an accurate triangulation across the island. It was found in computing the geographic positions from the southern station, across the island to the northern one, that the difference between the astronomic and the geodetic latitudes at the northern station was 56 seconds. The difference in latitude of these two stations is only about 30 minutes.

Similar situations might arise on any large island where the water of the ocean is very deep around it, because it is evident that the mass of the island attracts the plumb bob

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because of the deficiency of mass in the ocean and the mass of island above the sea.

The zenith to which all observations are referred in the determination of latitude and the meridian to which longitudes are referred are displaced by the local deflections and erroneous latitudes and longitudes are obtained in consequence. Thus the astronomic position is not referred to the spheroid or to what might be called the mean figure of the earth.

The triangulation data that are collected over a large group of islands will be of particular value in the determination of the figure of the earth and in investigations in the theory of isostasy which involve the determination of deviations from normal densities in the outer portion of the earth. Very little has been done in studying this subject of isostasy, using data collected in oceanic areas. This is a fertile field in which work should be done at an eary date.

It is very desirable to have determination of the elevations of mountain peaks and islands, and this could be done in conjunction with the observations for triangulation. All that is required is to observe the vertical angles on the peaks or islands at the time that horizontal angles are observed. The determination of these elevations will be of considerable assistance to navigators and also to engineers making surveys and maps.

GRAVITY ON LAND

One of the most important geophysical problems today is the determination of the intensity of gravity with the half-second pendulums. The accuracy of the determinations as made in a number of countries is of the order of one or two parts in a million. There are many gravity stations established on the borders of the Pacific, notably in the western states of the United States and in Japan. There are other stations established on islands or on the shores of continents, but it is desirable that greater activity in this line of work be carried on in the future. The observations for gravity consist simply in swinging a short pendulum, one-fourth meter in length, in a closed case from which nearly all the air has been extracted. The pendulum is set in motion and the number of swings that it makes in any given time, say 24 hours, is determined. With a knowledge of the time of oscillation at a new station and the time of oscillation of the same pendulum at some station at

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which the value of gravity is already known, it is a simple matter to compute the difference in gravity between the two stations.

Gravity is the term applied to the resultant of the force of gravitation, or the pull of the earth, and the centrifugal force due to the rotation of the earth. Accurate time observations are needed in this gravity work but they can be obtained with a wireless receiving apparatus from any one of the powerful stations from which time observations are sent out. In general, three days of continuous observation will give the value of gravity with an accuracy of about one or two parts in a million. It is possible to get a value of gravity that would be very valuable, but of somewhat less accuracy, by continuous observations of 24 hours. It may be that an observer could travel on a commercial steamer and get a value of gravity at a port at which the ship stopped for at least 24 hours.

Many groups of islands, like the Philippines or the Hawaiian islands, could very easily be covered by a gravimetric survey for the distance between the islands is comparatively short and commercial vessels ply between the various ports with sufficient frequency to make a campaign of gravity observations efficient.

There are a number of scientific uses to which gravity observations may be put. One is the determination of a gravity formula which will show the average variation of gravity with latitude. Such a formula is frequently used in physical and chemical laboratories and is also used by meteorologists and other scientists. Another use is for the determination of the shape of the earth. It is not possible to determine the size of the earth by gravity observations but even if the flattening or shape of the earth only can be obtained with greater accuracy than heretofore, much will have been accomplished.

The value of the flattening is needed by the geodesists in carrying on their work and also by astronomers in certain studies of the moon and planets. A third use of the gravity observations is the study of isostasy. It was explained above, under the heading "Triangulation," how the deflections of the vertical could be used in connection with the study of isostasy. That work can be supplemented by the studies involving the values of gravity.

The subject of isostasy is one that cannot be considered at length in this short article. Briefly it is the theory that the material above sea level is held in place by the fact that the

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column under any particular topographic feature contains material which is less dense than normal. This deficiency of density has been found to extend approximately to a depth of 95 kilometers.

The ocean beds are held in a position below mean sea level by the fact that the column immediately under any particular section of the ocean, down to a certain depth, say 95 kilometers, has material of greater density than normal. The theory of isostasy postulates that the mass in any unit column, whether under the ocean or an island or a continent, extending from the surface down to some depth, say about 95 kilometers below sea level, is the same as the mass in any other unit column. This theory of isostasy has become more than a geodetic problem; it is a geologic and also a geophysical matter, aside from its aspects as a geodetic problem. It is believed that much light can be thrown on the constitution of the outer portion of the earth under the ocean, if extensive new gravity stations on oceanic islands and along continental coasts are established.

GRAVITY AT SEA

A problem that has baffled geodesists for may years is the determination of gravity from a vessel at sea with sufficient accuracy to be valuable in geodetic studies. Attempts have been made from time to time with different classes of apparatus, but the results have not been as accurate as is necessary. Dr. O. Hecker, a German geodesist, some years ago determined gravity at sea with a boiling point thermometer apparatus but it is believed that the uncertainty in his results is at least 100 parts in one million. This is in striking contrast to the accuracy of the gravity determination on land, which is approximately one or two parts in a million.

Dr. Lyman J. Briggs, now of the Bureau of Standards, Washington, D. C., has devised an apparatus which in its essential principles consists of an air chamber held at a uniform temperature, and a column of mercury. The height of the column of mercury varies with the intensity of gravity. This apparatus gives results considerably more accurate than that of Dr. Hecker but still the accuracy is not sufficient. Other attempts to observe gravity at sea have been made: one of them being by Duffield of England. It is not known just what accuracy he obtained in his observations but it was probably not better than that of Briggs.

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Gravity observations have been made on Arctic ice by explorers, notably by Nansen during the trip of the *Fram* in its drift across the northern polar sea. An account of these observations is contained in the report on his expedition by Dr. Nansen. It is believed feasible to observe gravity accurately on an ice field, provided it is possible to secure accurate time observations. This can now be done by radio-telegraphy. Nansen used the ordinary pendulum apparatus in his observations.

The writer believes that it is feasible to determine the value of gravity at sea with the ordinary pendulum apparatus used on land. The apparatus should be suspended in gimbals and the pendulum should be swung in the vertical plane through the bow and stern of the vessel. If this were done on a vessel of considerable size, say of ten or fifteen thousand tonnage, during moderately smooth weather, it is reasonably certain that there should be no effect on the period of the pendulum due to the pitching of the vessel. In fact, with only moderate seas, such a vessel would have no pitch. A vessel will, of course, roll before it will pitch, but if the pendulums are swung in the direction of the bow and stern, a moderate roll would have very little effect on the pendulum. The effect of the roll of the ship can be much lessened by allowing the knife edge or the plane on which the pendulum head rests, to rotate about an axis placed longitudinally with the fore and aft axis of the ship. The pendulum could be standardized for various conditions that would be encountered on the ship.

One of the corrections that would have to be applied to the observing period of the pendulum would be the effect of what is called flexure. This motion of the pendulum case is due to the effect of the swing of the pendulum which is supported on a part of the case.

Time observations for the determination of the period of the pendulum could be received over the ship's wireless apparatus. This could be obtained from a number of observatories and thus the rates of the chronometers used in the gravity determination could be very accurately found.

It would, of course, be impossible to stop a large vessel for some hours in order to determine the value of gravity at a place on the ocean, but observations that would be well

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worth while and of considerable value could be obtained by observing the swing of a pendulum for one or two hours and by taking the mean value of the period of the pendulum as the value for the mean position of the vessel during the observations. There would, of course, be some error in this, but it would be comparatively small.

If such an apparatus is proved to be efficient it is hoped that one may be used in the near future, for values of gravity at sea which are accurate within about ten parts in a million are very much needed.

TIDAL OBSERVATIONS

There are a number of scientific reasons for carrying on tidal observations along the coasts and on the islands of the Pacific. Much work has been done in such places as the Philippine islands, Japan, Australia, and the United States in establishing the plane of mean sea level but it is desirable that a comprehensive plan be adopted which will throw light on the stability of the outer portion of the earth, erroneously called the crust by many scientists. It is not only necessary to establish the plane of mean sea level but this plane should be referred by precise leveling to substantial bench marks placed on ground that is not likely to be changed by the works of man or nature—that is local works of nature. I have in mind the desirability of extending the line of levels inland beyond the sedimentary material that has been unconsolidated. It is a well known fact that alluvial deposits of recent times do settle. This has been noticed in recent years on the delta of the Mississippi River, where lines of precise levels have been rerun after some years. The tidal bench marks should be placed on outcropping rocks or on land that has every appearance of being stable, as far as settling or shrinking due to local causes is concerned.

It requires approximately three years of continuous tidal observations to establish mean sea level with an error not greater than about one centimeter. Mean sea level should be established by such series of observations at frequent intervals along the continental coast of the Pacific, say at intervals of 100 miles or so, and observations should also be made on the larger islands of the Pacific. There may be an especial case where an island is very recent, due to volcanic activity, where a tidal station should be established for special reasons.

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At each of the stations the permanent bench marks should be established as is indicated above and at intervals of 10, 20 or some other number of years the precise leveling should be rerun with a view to ascertaining whether or not the relative elevations of the bench marks have changed. It would be advisable to have the bench marks located in such a way that it would be possible to get the difference in elevation in two directions. For instance, in a north and south direction and also in an east and west direction. This would show whether there was a tilting in any direction, while if all the bench marks were established along a straight line, there might be tilting of the surface which might escape detection by the rerunning of the line of levels.

Observations should be made continuously for an indefinite time at a few of the stations. At some of them tidal observations might well be repeated at intervals of a number of years. With a few stations running continuously, there would be means of learning whether there were regional changes in mean sea level. The writer does not feel that much can be learned in regard to the tilting of the earth in a short number of years. It may be that hundreds or thousands of years are necessary to show any decided changes in the relation of the firm ground back from the coasts and mean sea level or between an island and mean sea level, but it is well to start now a well considered plan which can be carried out for generations to come and modified as conditions may demand.

The cost of establishing a tidal station and keeping it in operation for three years would be very slight. The recording is automatic and would require only a few minutes of a person's time each day to wind the clocks and to make an observation of the staff, in order that the base line of the recording device may be known with relation to the record of the heights of water. The apparatus could easily be carried from place to place and established in a very few days at a small cost. It is believed that each nation, having Pacific shores and islands, would care for the tidal work of its own possessions, and it would not be necessary to have an international scientific body to carry on such work independently.

EARTH TIDES

A new kind of geodetic work has been developed in very recent years, namely the measurement of earth tides. This is a matter that had been given considerable attention by the old

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International Geodetic Association but the results obtained by their apparatus were not entirely satisfactory due to the limitations of the instrument. The problem of apparatus has been beautifully solved by Prof. A. A. Michelson of the University of Chicago. He has an earth-tide station at Williams Bay, Wisconsin, that has been in operation for some time and the observations there have been all that anyone may desire.

The apparatus consists essentially of two metal tubes, placed horizontally in the ground at a depth of about six feet in a north and south and in an east and west direction. These tubes are partly filled with water and the movement of the water in the tubes, due to the tide-producing changes of the sun and moon are observed by the interferometer method.

These observations show the yielding of the earth, under the tide-producing influences of the sun and moon. The water, of course, is free to move under these forces and the difference between the observed movement of the water and the movement that would take place on a perfectly rigid earth is a measure of the actual yielding of the earth itself.

From the results of these observations of Prof. Michelson certain physical properties of the earth's materials can be deduced, such as elasticity and viscosity.

The Director of the United States Coast and Geodetic Survery has had a conference with Prof. Michelson and tentative plans have been made relative to the establishment of a Michelson station at Honolulu, near the magnetic observatory of the Coast and Geodetic Survey. Prof. Michelson has outlined to the American Geophysical Union a plan which should be followed in making observations over the whole earth for the determination of earth tides. It necessarily contemplates observations along the coast of the continents and oceanic islands and in various countries of the earth to test the earth movements under the tide-producing forces in various areas. It is sincerely hoped that the Coast and Geodetic Survey may be able to carry out its plan to establish a station at Honolulu.

The cost of such a station would not be excessive, the principal expense being the purchase of the instruments and their installation, while the cost of maintenance would be almost nothing if the station were established near some other scientific laboratory or station where an observer could change the graphic record each week or at some other interval of time. The record

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is automatic and does not need hourly or daily attention by the observer.

There are other phases of geophysics which are of much interest to geodesists but they cannot be considered as strictly geodetic. Such are the studies in seismology and in certain phases of volcanology which furnish data for use in studying the question of the distribution of density in the outer portion of the earth. There are, of course, a number of phases of geology which are also of particular interest to the geodesists in the study of isostasy and the deflection of the vertical. Undoubtedly these phases of geophysical science will be cared for by the workers in those fields.

There is a geodetic work which I have not yet mentioned in this paper, because it does not materially affect the exploration of the Pacific. This is the variation of latitude. This is a subject of importance to geodesists and astronomers and undoubtedly will be taken care of by one of the international unions organized under the International Research Council at Brussels in 1919.

This paper is, of course, designed only to show the present condition of geodetic work in the Pacific, to outline in a very general way the problems in that area that are before the geodesist and to suggest methods and standards of accuracy which should be followed in attacking the vast problem before us.

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SURVEY OF SHORELINE AND COASTAL WATERS

By J. T. Watkins

The purpose of the survey of the shore line and the coastal waters is to collect the data required to map the topography of the coast region and chart the hydrography in all depths less than one thousand fathoms, together with other related oceanographic information.

The material gathered should be so complete and detailed that it will meet all the requirements of science, engineering and navigation, and serve as a basis for, or be supplementary to, the various operations conducted in connection with associated lines of scientific research.

The exploration of the Pacific region presents no problem which for interest, magnitude and importance surpasses the operations contemplated under this project.

The results here sought are eminently practical and of almost universal importance, through their direct bearing upon many vital economic interests and various scientific subjects. The navigator's dependence upon the charts and other hydrographic information resulting from such a survey need only be mentioned; and the interest of any one nation in that connection is not limited to the confines of its own coastal waters, but evidently extends to all regions penetrated by its commerce.

In some regions where surveys are very incomplete or entirely lacking traffic by water may be impracticable, if not forbidden; in other sections it may operate to retard local development; but in any case, in all unsurveyed waters a heavy and at time prohibitive tax is levied against trade through high insurance rates and excessive property losses.

The engineer's interest in hydrography and topography differs from that of the navigator only in degree and but slightly. His various construction problems in the region of tidal waters are frequently impossible of ready and satisfactory solution in the absence of such preliminary data as are afforded by the hydrographer and topographer. To the scientist the project is of prime importance as it will supply him data indispensable to his work in connection with the exploration of the Pacific and give to his local intensive studies a greater significance and broader interpretation. Many subjects of research in this field will profit by the work, whether they be physical oceanography,

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geology, meteorology, botany, ethnology, zoölogy or other sciences.

It is true that something has been accomplished along this line; submarine relief has been determined to some extent in certain limited areas, and incidentally considerable material has been collected on the subject of tides. But there has been no general plan adopted for the entire region, and in those relatively limited areas where a special effort has been made to complete the hydrographic survey, it is at once apparent from the published results that all the several subjects involved have not been developed systematically.

The published charts of the Pacific region show at once the relatively small part of the work accomplished, its incompleteness and haphazard distribution. In its relation to the project the proportion already done is rather insignificant and will constitute an unimportant factor in the formulation of programs and estimates for future operations.

The principal value of previous work is found in the important development of methods and means, which in many field processes have attained a high degree of effectiveness and efficiency.

In view of the magnitude, importance and urgency of the project, it is apparent that operations should be begun as soon as practicable and conducted vigorously in accordance with a comprehensive and consistent general program. Not only is there great need for immediate results; but many of the phenomena dealt with, such as shoreline changes, subsidence, emergence, tides and currents, are in a measure cyclic in occurrence and the characteristics of their periodicity can be determined, and the relation of cause and effect established, only through long series of continuous or intermittent observations. Such series of observations should be initiated at once so that the necessarily deferred final results may become available as early as practicable.

The fundamental operations of the survey are essentially mensurational and have to do largely with the determination of position or change of position in the vertical and horizontal planes. It is necessary therefore, in order to attain a desirable uniformity, to define and determine certain planes of reference to which all measurements may be referred without question or uncertainty. Horizontal position should be defined by geographic coördinates established by astronomical observations in conjunc-

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tion with a system of triangulation, and where feasible extended by triangulation or similar operations to furnish local control. The resulting permanently monumented local control points serve to establish present relations and to reveal changes due to differential movements of features. These operations are conducted with considerable facility on shore; but in off-shore work the attainment of a satisfactory degree of precision in the determination of horizontal position presents many difficulties; while in oceanic depths our present methods do not meet the requirements, especially when applied to the development of submarine relief; which is an added reason for a more thorough study of type forms in the shoaler waters and nearer the shore.

Elevations should be referred to mean sea level and all heights and vertical movements defined in relation to that reference surface as a common datum plane. This plane should be established by means of adequate series of continuous tidal observations at stations so distributed over the region that from them it will be readily possible to determine the plane at any desired immediate point. This local extension of the datum plane, or surface of reference, over the general region should be effected usually by means of precise levels and to a less extent by water levels; and in connection with all tidal and leveling operations there should be established permanent bench marks, sufficiently numerous to meet all requirements.

Based upon such horizontal and vertical control systems there should be executed a topographic survey of the coast region, extending inland to the head of tide-water, and, where that distance is relatively slight, then to the rather more stable interior which may be regarded ordinarily as beyond the influence of those agencies which operate to modify conditions in the coastal regions.

The shoreline should be determined with a degree of precision to meet all usual needs, except possibly those of the constructing engineer, and for him it should supply all data for reconnoissance and general location studies. The contoured relief should give the characteristic forms, varied in the amount of detail according to the importance of the locality: special note should be made of all evidences of relative movements of land and sea such as elevated beaches, submerged forests or other identifiable forms; cultural features are determined in order that horizontal and vertical movements and other changes in the

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region may be revealed by means of successive surveys, and such as are prominent or conspicuous features are carefully located and described for use as signals for other operations or as navigational aids.

Submarine relief in all cases should be developed in such detail as to show distinguishing characteristic forms; especially in their bearing upon the relation between the various features and the forces which operate to produce them; and to reveal the similarity and even identity of submarine and subaerial relief, where they exist. The character of the bottom should be determined and specimens collected where possible so that the materials encountered may be fully described and their distribution and occurrence outlined with certainty.

In this region forces operating through erosion, transportation and deposition are very active and it is necessary that intensive studies may be undertaken to reveal their laws in order that they may be controlled or utilized. The limitations upon such work are the depth encountered and the distance from shore. Operations of a high order of precision and giving much detail may be extended to depths of 100 fathoms, and off-shore to distances of 10 to 20 miles. Less satisfactory results are obtained when operating in depths of 100 to 500 fathoms and beyond the range of visibility of fixed signals; the limiting conditions are reached at about 1000 fathoms, where considerable dead-reckoning is involved. Beyond the 1000 fathoms curve neither detailed development nor precise position can reasonably be expected. It seems, however, an admissible assumption that the general conditions, in depths greater than 1000 fathoms, are of a more uniform character than those in shoaler waters and in consequence will not require the same close development.

In the inshore waters many changes are comparatively recent or are now in progress. Submerged topographic relief features frequently preserve their original forms or are but slightly modified. Changes in shoreline are taking place as shoals and fast land are modified. The differentiation of the causes of the several changes can be effected only by means of successive detailed surveys of the relief, in connection with redeterminations of mean sea level, and the various control reference points.

Vertical and horizontal movements of the water in tides and currents usually present problems of greater complexity in coastal regions than elsewhere. The gravitational, meteorological

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and other causes involved operate singly or in combination, under such widely varying configuration of the enclosing basin, that the resulting tides and currents are so complex that they will doubtless have to be given, as they certainly merit, more time and effort than will be required by any other oceanographic subject.

Tidal and current data should be so complete that cotidal and cocurrent lines may be drawn for all the waters covered by the survey; not only for time of occurrence, range and velocities, but for all the characteristics of the periodic, nonperiodic and seasonal changes in both horizontal and vertical movements of the waters.

Along with the survey of the submarine relief and tides and currents, systematic temperature and salinity observations should be made, and also the determination of such other physical chemical properties as may be feasible. These data, together with complete meteorological information, as far as possible, are indispensable to the interpretation of the tidal and current results, to which they are related as either cause or effect, in varying degree. The material collected should be of such a character as to supply all data required for its representation on charts by means of isotherms, isohalines, isobars, etc., and so extensive as to cover the entire region of the survey.

The topographic and hydrographic operations frequently offer excellent opportunities for work in terrestrial magnetism and though the determination of the characteristics of the terrestrial field may have only an incidental bearing upon hydrography, and even less upon topography, there are certain evident advantages resulting from conducting the operations simultaneously, as often the general magnetic reconnoissance made in this way could not otherwise be executed with equal facility, if at all. The program should include measurements of the declination, dip, intensity and secular change, for representation by means of isogenic and isodynamic diagrams co-extensive with the region of the work.

It is evident that the completion of the operations indicated marks the close of only the initial stage of the general survey. Not only are several of the phenomena under consideration of regular periodic occurrence, and their characteristics can be determined only by means of repeated surveys or long-continued observations; but many changes of more or less irregular

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occurrence will take place after the first survey and will require successive revisional surveys and inquiries into their causes. In regions subject to change or where change is suspected, check measurements will have to be made at intervals to establish the stability of conditions or detect movements in their incipiency. Many features developed in a rather general way by the survey may merit closer study and require detailed local surveys. Often data supplied for use in connection with other related subjects of research will in its new application reveal the need of a very considerable extension of the survey along some particular line, or indicate even the necessity of observations of a character not previously contemplated. Aside from all considerations of available means, we may therefore regard the work as not possible of completion in the near future.

These operations should embrace in their scope the entire Pacific region, and should be conducted in a systematic manner so as to give results of uniform character.

To accomplish this purpose it would seem desirable to carry on the work through some directing or advisory international coöperative organization created and supported by the countries interested. It is very desirable that this bureau include in its membership all private institutions contributing results that will aid in the solution of the problems involved in the exploration of the Pacific.

Such a bureau would be more likely to obtain prompt and satisfactory results, especially in localities which are of great scientific interest and little commercial importance. This same agency could very well undertake surveys required within the territorial limits of countries lacking means of doing such work. It could with propriety and advantage do much of the work necessary in extra-territorial areas.

Generally, however, it will not be the pleasure of a nation to have surveys within its territorial limits executed by any other organization than its own hydrographic bureau; or it may have unsurveyed areas of such commercial importance that it would be highly prejudicial to the national interests to await the probably considerably delayed execution of surveys in accordance with some general coöperative plan. It would therefore appear that surveys of this character should be made by the nations directly interested; but as far as possible, all independent work of this sort should conform to some general program adopted by the central directory and advisory bureau.

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Equipment for operations at sea will require special attention. It is not likely that any vessels now available will prove entirely satisfactory for hydrographic work, except the relatively few that were designed for the purpose and are now in service. Small naval craft and yachts may serve as makeshifts; but for continuous efficient service it will be necessary to build vessels for this specialized duty, and give due consideration to climate and other local conditions peculiar to the regions in which they will operate.

The instrumental outfit now available is susceptible of improvement in many ways, and merits serious consideration.

For the determination of position in off-shore work it is very desirable that observations should be made during the night and for this work some form of artificial horizon is required; several types that give promise of success are now developing. In this connection the wireless has worked a great improvement in all determinations involving time; but the results of its application in the radio-compass leave much to be accomplished. The more general use of sound-ranging devices for fixing positions outside the limit of visibility of signals, should be encouraged.

Depth determinations by means of reflected sound from the bottom are reported to be feasible; and though it may never supplant the standard method of sounding, there is a possibility of it becoming a valuable supplementary device.

In tides and currents much remains to be done; registering meters are still complicated and costly and their general use in extensive operations is not now practicable.

The much needed thermograph for serial temperatures has not yet developed beyond the experimental form.

Every phase of the work is of absorbing interest and the results are of immediate usefulness and almost universal application. The expense and time involved in the project, though considerable, are not at all disproportionate to the value of the data collected. Some lines of inquiry have only a present interest and a speculative future value; but the determination of the topography of the coast region, the submarine relief and materials of the bottom in the littoral zone, together with tides, currents, physical and chemical characteristics of the waters, and related or associated phenomena, is economically and humanely indispensable to the mariner and supplies the solid foundation for all oceanographic research.

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COMMENT BY MR. BOWIE

With regard to the mapping of shore lines, the big subject is how they are located. If we follow the methods of the geographical surveys of various countries which locate the shore line in such a way that it does not have to be reproduced from time to time, it is mapped once and need not be changed except in minor details. All continental shores should have one single geographical datum or starting point. The United States, Canada, and Mexico have adopted one single geographical datum for the whole of their areas. Accurate methods of mapping are not much more expensive than inaccurate methods, and while the latter is of little use, the former is invaluable. With a topographic map of the shore line we can work inland for many miles. Accurate geographical position and accurate shore line are fundamental.

In any survey the first, and one of the most essential requirements, is a proper location by longitude and latitude of all points of departure. In the old days there was no way of getting longitude accurately. The position of islands was determined by navigators using dead reckoning. The result was that a great many islands were shown in two or more positions. Today the simple means of getting longitude is by wireless telegraphy.

A letter recently received by Dr. Gregory from G. F. Dodwell of the Observatory at Adelaide, comes down to fundamentals:

I hope that among the subjects to be considered by the Conference the question of the more accurate determination of geographical positions of Pacific islands will find a place. We in Australia are planning a direct measurement of longitude difference between Greenwich and Australia (Sydney Observatory being chosen as our prime station at the end) by using wireless longitude signals from an intermediate station, capable of being heard simultaneously at both ends, combined with astronomical observations. We can now receive time signals very satisfactorily from Lyons, France, as a result of preliminary experiments recently carried out. The same principle applied to determinations of longitude of islands on various sea routes in the Pacific would, I think, be very advantageous. For several years I have been interested in fixing longitudes of reference points in South Australia, using a portable wireless receiving outfit, with which time signals from the observatory have been received, and the results of this method have been uniformly satisfactory. I shall be very glad to hear if anything of the similar nature is done in the Pacific as a result of your congress.

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MAGNETIC SURVEYS IN AUSTRALIA

By J. M. Baldwin, Government Astronomer,
Melbourne, Australia

(Presented by request of the Committee on Program)

The first magnetic observatory in Australia was that founded under the direction of Neumayer in Melbourne, systematic observations of terrestrial magnetism being commenced on May 1, 1858. These consisted of hourly readings of the three elements, declination, horizontal intensity and dip, and from the middle of July, 1858, absolute observations of the elements were made about once a month. The original site on Flagstaff Hill (now Flagstaff Gardens) rapidly became untenable and early in 1862 the station for absolute observations was transferred to the site where the present astronomical observatory stands. Neumayer completed his five-year programme of observations in 1863, and in December, 1863, the rest of the instruments were transferred to the newly-established Melbourne observatory. A very important part of Neumayer's work was the magnetic survey of Victoria carried out by him during the years 1858 to 1864. In this survey the total number of stations occupied was 230, distributed so that the greatest distance between neighboring stations is 30 miles and frequently only 18 or 20. The elevations ranged from sea-level to 7200 feet. The result of Neumayer's work is contained in four volumes,[1] the first two of which were published in Melbourne, the other two in Mannheim after his return to Germany.

At the new station the readings of the variation instruments were less frequent, but the work was carried on with the instruments used by Neumayer, until new instruments of the well known Kew form were received. The observations with the new absolute instruments were commenced in January, 1866, while the photographic registration with the variation

[1] 1. Results of the magnetical, nautical, and meteorological observations made and collected at the Flagstaff Observatory, Melbourne, March, 1858, to February, 1859; 2. Results of the meteorological observations taken in the colony of Victoria during the years 1859 to 1862; 3. Discussion of the meteorological and magnetical observations made at the Flagstaff Observatory, Melbourne, during the years 1858 to 1862; 4. Results of the magnetic survey of the Colony of Victoria executed during the years 1858 to 1864.

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instruments was commenced in November, 1867. This work was continued without interference until about 1909, when the effects of electric traction began to show on the records, and it was evident that before long the Melbourne site would become quite unsuitable. Not long after, efforts were made to obtain a new building in an undisturbed area, but it was not until August, 1919, that the new observatory was completed and the instruments recording. The new variation building, situated at Toolangi (Longitude 145° 28′ E, Latitude 37° 32′ S) some 38 miles northeast of the Melbourne Observatory, follows closely the general plan of the United States Coast & Geodetic Survey Magnetic Observatories, the instruments being of the Eschenhagen type, recording declination, horizontal force and vertical force. The absolute observations are still made in Melbourne with the same magnetometer, but the dip circle has been replaced by an earth inductor by Schulze which has been in use since January, 1916. This work also will be transferred to Toolangi in the present year, as soon as a suitable building can be erected. None of the variation observations made at the Melbourne Observatory have yet been published, nor is any assistance available for their further reduction.

A general magnetic survey of Australia was carried out by the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, commencing in July, 1911, and lasting about four years. In this time over 400 stations, as evenly distributed as circumstances would permit, were occupied. The earlier data obtained have been published by the Carnegie Institution, in "Land Magnetic Observations," 1911 to 1913, and the remainder will appear in a later volume. Several additional stations have been occupied in South Australia in the last few years by the Adelaide Observatory, and the number of such stations is being gradually increased as opportunity offers.

On the conclusion of the general magnetic survey of Australia, the Carnegie Institution erected a magnetic observatory at Watheroo, Western Australia (Longitude 115° 52′ 38″ E, Latitude 30° 18′ 56″ S), and this observatory has been in active operation since January 1, 1919. Although at present the work is confined to terrestrial magnetism, the site has been chosen with a view to extending the work in several directions, the complete scheme involving work in (a) ter-

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restrial magnetism, (b) atmospheric electricity, (c) earth currents, (d) possible solar constant observations. The design of the magnetic variation observatory follows the general lines adopted by the United States Coast & Geodetic Survey, the room containing the recording instruments being large enough to accommodate an eye reading and a self-registering set of Eschenhagen variometers, while the house itself measures 16 feet by 32 feet, so that a magnetometer and an earth inductor and galvanometer can be mounted at either end without interfering with instruments at the other end. The magnetometer used is of the Survey of India type modified by the Department, and a Schulze earth-inductor with Plath galvanometer.

THE GENERAL SCIENTIFIC AND PRACTICAL PROBLEMS OF OCEAN MAGNETIC SURVEYS

BY LOUIS A. BAUER, Director, Department of Terrestrial Magnetism, Carnegie Institution of Washington

At the request of the Committee on Program, Dr. Bauer submitted a paper giving the results of his personal experience in the conduct and direction of magnetic surveys on land and sea, covering a period of 26 years. Fuller statements appear in Researches, Department of Terrestrial Magnetism and Yearbooks of the Carnegie Institution of Washington.

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DISCUSSION ON MAPPING THE PACIFIC

By Members of the Conference

[The following contributions have been abstracted from the stenographic report of the Proceedings.]

Mr. Bowie: Whenever a scientist makes an investigation of any part of the earth's surface he needs to know the geographic positions of the various topographic features included in the area and also the elevation and the slopes of ground between them. All of this information is contained in the modern topographic map such as is made by each of the well organized nations of the world.

The topographic map is needed in all branches of what may be called the "outside sciences" such as biology, geology, geodesy, meterorology, ethnology, etc. No scientist working in any area would attempt to carry on intensive investigations without first making at least a rough topographic map if no better map were already in existence. In fact, it may be said that there is scarcely a human activity that is not in some way affected directly or indirectly by the presence or absence of accurate maps. It is impossible to search effectively for the treasures of the earth in the form of minerals, including oil and coal, forests, water power, soil fertility, unless we have a knowledge of the configuration of the earth's surface. It is therefore clear that the nations of the world should start a movement to expedite the completion of the topographic mapping of their areas. With accurate topographic maps the scientists and engineers can discover the natural resources and locate them on the maps; then by utilizing these maps, which show the location of the topographic features and the configuration of the ground, plans can be made for the best economic development, utilization and conservation of the natural resources. It is reasonably certain that millions of dollars yearly would be saved to investors, who support financially projects for the development of natural resources in areas where such development is exceedingly costly, if the conditions had been previously revealed by adequate topographic maps.

What is said above applies particularly to the Pacific region because of the vast resources in the countries bordering that great ocean and in the islands contained within its area and also because of the large population that inhabits the region.

It is very desirable that in any large area such as the Pacific basin some uniformity in methods should be followed in carrying on topographic surveying and mapping. It is probable that any organization created for scientific investigations in the Pacific will have topographers as representatives from each of the countries and they should form a branch or section of the central oranization. It is desirable that this section should provide standards of accuracy in the surveying and mapping and should make recommendations to the various countries in regard to the units of length used for horizontal and vertical distances as shown on the maps. If there were uniformity in the topographic mapping of the countries of the Pacific the scientist or engineer could operate in any part of the region without being confused by different topographic symbols, different scales and different degrees of accuracy in each country. The question of the projection to be followed for the topographic maps is a very important matter and should also be considered

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Of course, no international body such as a scientific organization can dictate to any country what it must do in its own area but it can give very valuable information which should be very gladly received by any country. Very little has been done in the Pacific basin in making accurate topographic maps and it is possible that this line of work will be carried on more rapidly in the future than in the past.

Some progress has been made in covering the world with maps which will be of considerable value to scientists. The maritime nations of the world had representatives at a conference in London in 1909, at which plans were adopted for the construction of a world map to be used by all nations. This map, known as the International Map of the World, is now being constructed by a large number of countries. Its scale is one part in one million and every map sheet will cover an area of 6° of longitude and 4° of latitude. Each country taking part in the conference of London pledged itself to construct maps of its own domains in accordance with the plan adopted and to carry on the work as rapidly as possible.

Scientists, engineers and others whose efforts are benefited by accurate topographic maps are urged to interest others in the importance of topographic mapping of their own country. It is reasonably certain that any efforts expended in topographic mapping will bring most gratifying returns of great value and benefit to humanity.

BAILY WILLIS (abstract from a letter): Were I to take part in your deliberations I would be governed, so far as our own particular science is concerned, by the concept that the geology of the Pacific is a distinct unit, that the chain of similar and essentially contemporaneous phenomena runs around its shores from the East Indies, through Japan, Alaska, and both Americas to Cape Horn. Through this vast periphery there should be reconnaissance work to develop or disprove the concept of unity, and at carefully selected key localities there should be detailed investigation to provide the clues for more extended careful research. And this work should cover all branches of geology, stratigraphy, structure, paleontology, petrography, and physiography.

MR. BEALS: (Abstract prepared by the author.) My interest in the scientific exploration of the Pacific Ocean pertains to meteorology, and especially to that branch which has for its object the forecasting of the weather. You probably know that very little increase in the accuracy of weather forecasts has taken place in the last quarter of a century. This is due to the fact that there has been no marked extension in the field of observations during that time. We have kept using the same data year in and year out, until we have worked about all there is to be had out of it, at least from a forecasting standpoint.

For forecasting purposes meteorological observations should be taken at the same moment of time over as large an area as possible. After they are taken, it is necessary that they be transmitted very quickly to some central point. They are then charted and viewed by the forecaster, who makes his deductions as to the weather expected for as long a time ahead as he thinks can be done without impairing the accuracy of his forecast.

United States Weather Bureau predictions are correct about six out of seven times. The bigger and more general the storm the greater is the probability of the forecast being correct. It is the minor disturbances that are most often missed by the forecaster.

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The practical benefits derived from these forecasts are very great as there is scarcely a business that is not affected by them. Probably the greatest benefits are reaped by the transportation interests both on land and sea. Next comes the agricultural and manufacturing interests, and these are followed by those pertaining to health, pleasure, etc.

It is obvious to all that the longer ahead forecasts can be made without impairing their accuracy, the greater will be the benefits derived from them.

It is the opinion of the weather forecasters in the United States, which is the only nation I can speak for, that if weather reports can be received with dispatch from the little known regions in the North Pacific Ocean, it will be possible to materially increase the accuracy of weather forecasts in the United States, and at the same time extend their period of application. The papers presented to the Section on Meteorology give the reasons in detail for believing this can be done.

Owing to my time being so limited only the briefest outline of the project can be given here. There are two meteorological centers of action in the North Pacific Ocean. One is called the semi-permanent Aleutian Low pressure area, and the other is known as the permanent High pressure area. When the Aleutian Low pressure area is below normal and the High pressure area is above normal, unusually high temperatures prevail in the United States, especially to the westward of the Mississippi River. When the contrary conditions exist unusually cold weather prevails over the western half of the United States and generally abundant rain falls in the Pacific States.

It is my opinion that if a few vessels equipped with radio outfits and meteorological apparatus were assigned to fixed stations, or as nearly fixed as practicable in the least known regions of the North Pacific Ocean, that weather reports from them would be of incalculable value for forecasting purposes. Also masters of vessels equipped with radio outfits sailing over the well known routes between America and the Orient, should be invited to send radio reports of the weather from their ships at least twice a day to designated forecast centers. These reports would supplement the others and be of additional help to the forecasters. Also it is believed a land station of the first order should be established on one of the westernmost of the Aleutian Islands, which station should be provided with a radio outfit for transmitting weather reports.

A service such as outlined could be utilized for other scientific work, such as might be desired by the oceanographer, by the men interested in terrestrial magnetism, and the mapping of ocean depths.

MR. RICHARDS: It is quite apparent that the mapping of the Pacific Ocean concerns all of us around that ocean. The information to be derived from a correct and thorough mapping is varied and although the need of this has been stressed by speakers from North America, the same arguments with perhaps greater force might be used by people from the southwestern Pacific.

The mere charting of coast lines, islands and shoals is insufficient. The mapping of the floor of the ocean is in some ways more important than that of the shoals and coasts.

We have from time to time on the eastern coast of Australia seismic disturbances which result from the slipping down of material over a submarine shelf which lies to the northeast of Australia and probably marks the original rim of the Pacific Ocean. The

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mapping of such shelves and the deeps adjacent is not only of much interest but is of great importance.

It is of interest to me to learn of the work being carried on along the California coast with respect to the development of shoals and bars. The northern rivers of New South Wales and some other Australian streams are very much bar-bound and the New South Wales government has spent over £1,000,000 sterling on the two river mouths without any success. If the plan of operation of the currents were understood, the source of the sand forming the bar known, and the factors governing its distribution really established, we would have data of the greatest economic importance.

The marine biological wealth of such places as the Great Barrier Reef is largely unknown; much remains to be learned in that direction so that it may be exploited not only profitably but judiciously.

It is quite clear, therefore, that there are many reasons for thoroughly mapping the Pacific other than the determination of coast lines and shoals.

MR. VAUGHAN: There are certain things in mapping the Pacific that are of particular interest to the geologist. I will mention a few of them. One is the sediments on the floor of the ocean. Information regarding bottom deposits is deficient in the same degree as information on the deeps concerning which Mr. Littlehales has spoken. Bottom samples should be taken at the same interval as that at which soundings are made.

Other factors that influence sedimentation than those considered in the reports of the *Challenger* Expedition, now need to be considered, because there has been considerable refinement in methods of study since that time. One of these is the exceedingly close interrelationship between the chemical composition of the sea water and the material that occurs on the sea floor, particularly the relation between the acidity and temperature of the water and the characters of the bottom material.

Leaving the deep sea and coming to the shallow water, it is now known that much of the calcium-carbonate deposits in the shallow waters of the tropics have no coral in them. For any work on these samples we need to know much more than the chemical composition. Clarke and Wheeler have rendered valuable service in their work on the chemical composition of the skeletons of marine invertebrates because they show that the chemical composition of a sediment varies according to the organisms contributing material to it. Bottom specimens need to be studied very carefully to ascertain the percentage of the material contributed by different agencies, both organic and inorganic. I would urge that bottom samples be collected at close intervals, that both the chemical and mechanical composition be studied more carefully, and that more information be obtained on the agencies that are contributing material to the bottom deposits.

In regard to the configuration of the sea bottom it is obvious that knowledge of the major configuration of the sea-floor is important because of its value in interpreting geological history. But in certain areas more information is needed than that on the major configuration of the sea floor. Around all islands and along the continental shores detailed information on the submarine slopes of the continents and islands is necessary for elucidating geological history. The scale of the resulting maps need not be the same for all areas: 1:80,000 for example is sufficient for some areas; but in many areas, for instance, where there are coral reefs, the scale should be 1:20,000 or even 1:10,000. In places the coral reefs are growing on terraces or submerged flats for the study

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of which very detailed maps are needed. Several areas around the Hawaiian islands should be mapped in great detail, for instance the flat that extends westward from Molokai.

MR. GREGORY: In my opinion topographic mapping of the shores and islands of the Pacific should take precedence over most other kinds of geographic work. At present the ethnologist, botanist, zoölogist and geologist, as well as the geographer and engineer, are seriously handicapped. Teachers likewise lack suitable maps for class instruction.

Mapping of this big region—a third of the earth's surface—is beyond the financial ability of institutions. It is a job for governments and I consider it our duty to urge the various nations to undertake it. What a service to mankind if the navies of Japan, the Netherlands, Australia, New Zealand, France, Chili and the United States would devote their surplus energies to mapping the Pacific!

MR. DAVIS: When Columbus endeavored to enlist the aid of Queen Isabella for his explorations he showed her a map of what he thought he would find. Unlike Columbus, the man of today wants a map of what is known. When a scientist takes up work in a new area, he first collects all the maps available. In our country he goes to the United States Geological Survey for his land maps. If the territory has been covered by a map it is of great value to him in laying out his plans of endeavor.

There are available maps of the mainland along the Pacific coast. Inland from the coast from San Francisco north to Puget Sound are a few scattering maps, and the same can be said of Alaska. The coast line, of course, is well mapped by the Coast and Geodetic Survey and the triangulation carried out in all these are by the Coast and Geodetic Survey. We use these altogether. Also in the Hawaiian islands the territory is all covered by the Coast and Geodetic Survey triangulation. We started mapping the islands in 1909 and continued until 1915. We finished the island of Kauai and some of the island of Hawaii. Oahu had already been mapped by the army engineers and we were allowed to take their maps and reduce them and print them for the use of the public. We have commenced new mapping south of the volcano on Hawaii and hope to continue work on that island as well as the others until it is completed.

[Mr. Davis exhibited a number of topographic maps illustrating his remarks.]

MR. YAMASAKI: In response to the request of the Committee on Program, I have prepared this list of topographic surveys of Japan:

IMPERIAL MILITARY SURVEY; TOPOGRAPHICAL CONTOUR MAPS (JAPANESE EDITION ONLY)

1:20,000	Most parts of Japan already published, rather old edition.
1:50,000	Most parts of Japan already published, new edition, mono- and tri-color.
1:25,000	Some parts of Japan already published, new edition.
1:200,000	"Taikokudzu" or Imperial Map, new edition; most parts of Japan already published.
1:1,000,000	"International Map" in English; only two sheets published.
1:1,000,000	"Tōo yochidzu" or map of Eastern Asia, including most parts of China, some parts of Siberia and Japan.

IMPERIAL GEOLOGICAL SURVEY OF JAPAN; TOPOGRAPHICAL AND GEOLOGICAL MAPS (JAPANESE AND ENGLISH EDITIONS)

1:1,000,000	Korea and Sakhalin not included.

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1:400,000	Five large sheets including Houshu, Shikoku and Kyushu.
1:200,000	Many sheets; all parts of Houshu, Shikoku and Kyushu.

PREFECTURAL GOVERNMENT OF HOKKAIDO

1:200,000 Topographical map in Japanese only.

GOVERNMENT-GENERAL OF TAIWAN (FORMOSA)

1:400,000 Topographical and geological maps.

GOVERNMENT-GENERAL OF CHOSEN (KOREA)

1:50,000 Topographical maps published for all parts of Korea.

MR. THOMSON, Chairman of the Session: I have been rather surprised to have heard nothing in the discussion of shore lines regarding the southern coast of the Pacific, the shores of the Antarctic land or lands west of South America. That is an almost unknown area. There have been various expeditions to the Antarctic, but none have been able to land or observe the shore-line west of Graham's Land. Captain Scott thought he found land, King Edward VII Land, at the eastern end of the Great Ice Barrier, but was unable to make a landing or to rediscover the supposed land on a subsequent expedition. So there remains a large gap. This region is very interesting from the point of view of structure, because the Andean type of folded mountain continues into Graham's Land, whereas a plateau type is found around Ross Sea. There is room for good charting work in this part of the Antarctic by an expedition with airplanes.

With regard to wireless determination of longitude, a longitude of Tahiti was recently made by simultaneous wireless signals from Wellington, New Zealand and from San Francisco.

I recently tried to draw a map of the Antarctic and South Pacific oceans for a report on the brachiopods of the Australian Antarctic Expedition. You have heard today that soundings should be not 100, but 10 miles apart. If the soundings in these southern seas had been as near as 500 miles apart I should have had more confidence in my contours. The 1000-fathom line north of New Zealand, as given in current maps, is so extraordinary that I cannot believe it to be true. I have not studied the charts with the soundings on which the long narrow ridges above 1000 fathoms have been based, but I should imagine that there is a great deal of guesswork about the lines, and that much more detailed charting needs to be done.

Both in the South Atlantic and to a less extent in the South Pacific, submarine elevations are shown above the 1000 fathom line bearing no islands. The shape of these would be very interesting but is not known. In charting the bottom certain areas ought to be studied more than others because a great problem is involved. There is an interesting biological point in regard to a submarine bank. Such forms as brachiopods, which are not distributed by free-swimming larvae and are restricted to depths above the 1000 fathom line cannot cross the deep and wide oceans. Where they do, it is good evidence of an earlier land connection. What are the fauna on these submarine banks? We do not know. If these banks are drowned lands, we should have the remains of coastal faunae. If they are diastrophic uplifts of the deep bottoms they can bear only forms of distinct type which have crept up from the abysses. It seems to me that you have there a biological test of the theory of the permanence of ocean basins. The determination of the fauna and contour of these submarine banks should be studied in mapping out the Pacific.

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The bottom waters of the ocean, we are told, creep from the poles and bring the oxygen to the ocean bottom. We know there are enclosed areas like the Black Sea where there is no oxygen, where there is a foul bottom caused by the absence of bottom scavengers, and where sulphur bacteria thrive and precipitate calcium carbonate as a fine mud. Is it possible that there could be a foul bottom in the deep sea? We have in New Zealand an Eocene or late Cretaceous limestone, up to 2500 feet which is composed mostly of fine calcareous mud, with relatively few foraminifera, and no large fossils of the chalk type. The puzzle is how it was formed. I have suggested that it was formed by chemical precipitation. What kind of deposits are forming in the deeps cut off from the polar bottom creep?

In New Zealand there is very little known about marine currents, salinity, temperature and acidity. It is of very great importance to a knowledge of our fisheries. The fishes appear sometimes in great quantities and are sometimes very scarce. On economic grounds alone the charting of the Pacific will be good business.

MR. WELLS: The reference made by Mr. Thomson to the calcareous mud found at the bottom of the Black Sea recalls another striking characteristic of that region. I refer to the presence of hydrogen sulphide. It is supposed that this gas is produced by bacteria that reduce the sulphates of sea water to sulphur or sulphides. As a matter of fact the presence of hydrogen sulphide in the water shows that the oxygen has been exhausted and indicates a lack of circulation in the bottom waters. The acidity produced by hydrogen sulphide in natural waters is comparable to that produced by carbon dioxide, as the sulphides are quite comparable to the carbonates in regulating the various equilibria that determine the so-called acidity of such waters. The occasional existence of unusual conditions, such as those found in the Black Sea, shows that chemical determinations of the gases in sea-water should be made wherever possible along with the other determinations, such as those of depth and temperature, which this Conference will urge as essential for a scientific understanding of the problems of the Pacific. The few scattered determinations now available show irregularities that demand further investigation.

Further studies are also needed of the waters held in the muds and the organic matter of the bottom. These waters carry an excess of carbon dioxide, as Murray and Irvine found, and possibly an excess of ammonia, which would greatly affect the permanency of a deposit of calcium carbonate. The complete solution of this problem requires an evaluation of the solubility-product of calcium carbonate, that is, the product of the concentrations of the calcium ions and the carbonate ions. Although it is an easy matter to determine the concentrations of the radicals present in sea-water it is more difficult to evaluate the concentrations of the ions and it is these quantities that determine the solubility of calcium carbonate. Chemists, however, are making progress in these matters and it is hoped that better apparatus will also be perfected shortly for taking samples from the oceanic floors, especially at great depths.

MR. FRASER: In connection with deposition and sedimentation, the effect of rivers is important in such areas as British Columbia and Alaska where currents are deflected by a series of islands. A study of sediment brought down by large rivers is of the greatest interest from the standpoint of the formation of the sea bottom and from a biological standpoint. Large rivers bring down organic as well as inorganic material to their mouths which are the greatest feeding grounds of fishes and other forms of life. In British Columbia there are 7,000 miles of regular

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coast line and there are so many islands that each area is a study in itself. If the work were carried on as Commander Watkins has indicated it would give us much information about the shore area which from the food standpoint is more important than the deep waters.

MR. MAYOR: There are enormous deposits of limestone in the Atlantic. I have not seen them in the Pacific. Sea water is supersaturated with calcium carbonate—there is plenty of it in the waters about Tutuila—and the question is, why is it not precipitated? In the tropical Pacific there is practically no seaweed, but there is a great deal in the Atlantic. There is also an absence of nitrates in the Pacific which may account for the paucity of seaweed. The absence of precipitated calcium carbonate is correlated with the absence of seaweed. Seaweeds may cause the precipitation of limestone.

MR. COTTON: I would like to add a line to Mr. Richards' remarks about Antarctic meteorology. In Australia the importance of knowing weather conditions is very great and forecasting has therefore great value but the meteorological station at Macquarie Island has been abandoned. It should be reëstablished, and I believe that if this Conference could be impressed with the importance of that station, we could get it reëtablished. South of 45 degrees south latitude is about one-fifth of the earth's surface in which practically nothing is known in regard to meteorological conditions except such observations as have been made by exploring expeditions and at Macquarie Island. Macquarie Island is probably the most suitable place in the South Pacific for a meteorological station. The maintenance of such a station would not only benefit Australia and New Zealand in enabling us to have better forecasts, but would benefit all the world in the study of the atmospheric circultaion of the globe.

MR. MOORE: I have listened to these papers this morning with the greatest interest for the subject is one of prime importance to the fisheries. Of course it is important to the fishermen from the standpoint of navigation to have accurate charts of the Pacific, but it is not that phase of the matter that I have particularly in mind, but the benefits to the fisheries themselves. I had the privilege a few days ago of making some brief remarks on the subject of the effects of ocean currents on fisheries. I believe that those effects are greater than I indicated at that time. But there is another phase of the matter which is important. The fisheries are mainly carried on on the continental shelf or on the banks arising from it or adjacent to it. The surveys that are made for navigation are in most cases confined to the limits of the continental shelf. Ordinarily the survey is conducted to a depth of 100 or 180 fathoms, quite enough for navigation. On the Atlantic coast these surveys are also quite adequate to serve the purposes of the fisheries for the depths increase slowly; but I do not think this is true of the Pacific coast of the United States or Canada. Fishermen tell us of banks lying far out to sea, particularly near Puget Sound and the Straits of Juan de Fuca. In many cases the reports of these banks may have been based on the presence of discolored water, which is an unreliable indication, but there is probability that such banks do actually exist. They do not come close enough to the surface to require attention from the standpoint of navigation, but they may affect fishing.

Several years ago, with the *Albatross* we ran three lines of soundings 300 to 350 miles south of west of Cape Flattery. The normal depth was from 1500 to 1600 fathoms, but we found soundings of 500 to 600 fathoms, indicating that a peak arose from the bottom of the sea to a height of about a mile. Similar cases probably exist elsewhere where the bottom rises close enough to the surface to permit fishing for halibut.

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The movements of the halibut indicate that there must be some such shallow off-shore banks to which they go when they disappear at times from the coast. I was therefore interested in what Mr. Watkins had to say about the proposed survey of the Pacific coast, that in his opinion it should be carried to a depth of 1000 fathoms. From the fisheries standpoint as well as from the standpoint of general scientific interest, I believe that the government and other institutions interested in fisheries should carry out such a survey.

I was interested in Dr. Vaughan's remarks concerning bottom deposits. They are now inadequately mapped for fishery purposes. I have said that fishing is conducted on the continental shelves, but that is true only in certain places and certain regions. Large areas of the continental shelves are barren of fishes whose distribution is largely conditioned by the character of the bottom and by the character of the organisms that exist there. Where there are shifting sands there would not be many fish; but where bottom-dwelling organisms can fix themselves without danger of being buried in sand, we have a bottom fauna which attracts the fish for the food which it affords.

We are also interested in all the phenomena which might be collected by those making physical surveys. We want to know much more about the currents, salinity, temperature and acidity of the water, and also of the penetration of light in the water. We should also know more about the light that reaches the surface. Light is absorbed as it goes down deeper into the sea, but the light of different wave lengths is absorbed in different proportions, the red rays being separated out first and the violet being perceptible to a greater distance. It appears to me to be probable that in the passage of light through the fog banks over the sea, we have something of this kind. We know that during fogs the total light reaching the surface of the sea is reduced but the difference is still greater in the composition of that light owing to selective absorption. That is important in its effect on the vegetation of the sea and indirectly on marine animals which serve as the food of fishes. I think that possibly as a result of a study of that question we might be able to explain some of the peculiarities we have observed in the seasonable distribution of fishes. During some seasons certain fishes are scarce or absent, a fact that may be correlated with the paucity of plankton. That condition may be due in part to the quantity and quality of the light at and near the surface of the sea.

I wish to emphasize this: insofar as the improvement of the fisheries is concerned, we are handicapped by a lack of knowledge of these fundamental physical data such as the surveys discussed this morning would give us.

MR. BARTSCH: I think Dr. Moore has well pointed out the application that can be made of oceanographic studies to the economic fisheries. The marine invertebrate problem, which after all is a part of the fisheries' problem since marine invertebrates furnish the greater part of the food for fishes, is in every way similar to that of the fish fauna.

We are puzzled to know why certain organisms are found only in certain places, and I believe that the underlying factors can be determined only by coöperation with other agencies. The Weather Bureau can undoubtedly furnish a large amount of data that can be directly correlated with the determination of ocean currents. Then comes the oceanographer with his knowledge of currents of which we know only the surface streams at present. Then comes the element of chemistry. We know that as far as land forms are concerned, certain organisms are so delicately balanced that if you shift them a little bit, out they go. There

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is probably no difference in marine creatures in this respect, and it is possible that the same law may govern both.

As far as I have been able to discover, mapping has been largely actuated by one viewpoint, namely, that of keeping ships from running aground. In the United States the Bureau of Fisheries stands practically alone in oceanographic efforts along other lines. I fear that if we are to understand the basic laws that underlie the life histories and distribution of marine organisms, we must have subsea topographic mapping just as we have topographic mapping on the land. We must have not only contours but a knowledge of the environmental conditions that obtain in the various places.

Let me point out a few of the specific problems that worry me at present. On the coast of California we have a decided break in the distribution of littoral marine mollusks at Point Conception. South of there we have a series of islands: San Miguel, Santa Rosa, Santa Cruz, San Nicolas, San Clemente, etc., to Guadeloupe. On these islands we have land mollusks of the *Epiphragmophora newcombei* and the *Epiphragmophora facta* group. There is a great difference in environmental conditions on these islands, but not so in the faunal elements which are the same on all the islands, and entirely distinct from the elements that occur on the mainland. The question of how these shells came to occupy their present range is an interesting one. A subsea topographic survey would probably tell us that there exists a plateau that may connect all these islands which represent merely the peaks of mountains, while a marine biological survey might tell us that the Oregonian faunal area may stretch on the outside of this submarine plateau away south of Point Conception. It is even possible that it might suggest that this now submerged mountain chain might have enclosed a gulf which embraces what we have called the Californic faunal area in which this fauna became differentiated in times gone by.

When it comes to other oceanographic data, what a help it would be to us to know the changes which we find in the temperature conditions or the chemical constituents of the water along the coast. I remember I was deeply puzzled in trying to understand why one Odostomia which occupied littoral water was also found at one station in 400 fathoms off shore. I felt that my perception was wrong in not differentiating it specifically; but I examined the specimens again and again and found them to be absolutely the same thing. An examination of the hydrographic data furnished by the U. S. Bureau of Fisheries, the material having been collected by the *Albatross*, showed that the same salinity conditions existed in the two places. There then was the clue why the same species was found in both places.

If we had careful subsea mapping we would find great deeps in certain regions which would show that something had gone down, that block faulting had taken place, and we could thus understand more easily the bridges or stepping stones over which land faunas have traveled.

There is not a single oceanographic or topographic element which has been discussed that does not throw light on our zoölogical problems. What we need is more of such information, and then still more of it.

MR. VAUGHAN: In regard to the action of bacteria, I will refer to history prior to the original cultures to find the effect bacteria would have in the precipitation of calcium carbonate. In my first work on the bottom deposits of Florida waters I pointed out that a considerable proportion of the calcium-carbonate bottom deposits of that region was due

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to chemical precipitation. When Drew had found that the denitrifying bacteria on which he was working produced ammonia I suggested that he had probably found the agency responsible for the precipitation of the calcium carbonate and he began to make cultures to ascertain what effect the denitrifying bacteria might have. My suggestion was based upon work of Sir John Murray, namely, that the precipitation was due to the interaction of ammonium carbonate and calcium sulphate. The important activity of the bacteria is that they lead to the formation of ammonium carbonate. Any other bacteria than denitrifiers that will produce ammonia will bring about the precipitation of calcium, if there is also a source of carbon dioxide.

Although bacteria are important agents in causing the precipitation of calcium carbonate and are probably the most important, they are not the only agents. The agents that can produce precipitation may be summarized as follows: (1) ammonifying bacteria in the presence of carbon dioxide; (2) anything that tends to increase the concentration of salts in the sea water like evaporation; (3) heat; (4) green plants.

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OCEAN CURRENTS

THE STATUS OF OCEANOGRAPHIC STUDIES OF THE PACIFIC

By George F. McEwen.

HISTORICAL SKETCH

The Atlantic and Indian oceans have been repeatedly traversed by representatives of Occidental civilization since the fifteenth century, but the rapid rise of the Pacific to a place of importance to the world at large dates from the year 1850. Until the nineteenth century, all regions of the Pacific except a few islands contiguous to the coast of Asia, remained almost severed from the economic and commercial life of the civilized world.

On September 29th, 1513, Balboa saw from a mountain top on the Isthmus of Panama a vast expanse of water extending westward. This was the Pacific ocean, sought in vain by Columbus in his attempt to find a passage to the East Indies. Four years later, in 1517, Balboa with great enterprise and labor succeeded in transporting timbers and other materials of his ship from the Atlantic to the Pacific side where it was rebuilt, thus making it possible for him to sail on the great ocean which he had discovered. On November 27th, 1520, Magellan, proceeding southward along the Atlantic coast of South America, passed through the strait which now bears his name, and was the first European to sail on the calm southern waters of the new ocean, which he called the Mar Pacifico or Pacific Ocean.

An era of geographical exploration followed the enterprising voyage of Magellan. In 1567 Alvaro de Mardana discovered the Solomon Islands, and ten years later, Sir Francis Drake, the first Englishman to sail the Pacific, passed through the Strait of Magellan while on his famous three year voyage around the world.

The 17th century marked the discovery of Australia, New Zealand, Tasmania, and many smaller groups of islands. But enormous errors in estimating longitude often necessitated weeks of search for islands and archipelagoes whose positions were recorded by earlier navigators. However, this serious difficulty began to be remedied after the year 1766, when Wallis intro-

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duced the method of lunar distances in determining longitudes. In the 18th century the famous voyages of Anson, Bass, Behring, Cook, La Perouse and others resulted in the completion of the more important geographical explorations in the Pacific. And by 1827 through the memorable voyages of Carteret, de Bougainville, Vancouver, and Dumont d'Urville the geographic work of ocean research was completed in all of its main features. After this period of the spectacular discoveries later explorers were active in obtaining further geographical details.

Also the painstaking operation of coast survey departments of the different nations have continued for the past century to perfect our knowledge of coastal details. But much remains to be done in fixing more accurately the position of island groups, tracing more carefully the outlines of coasts, determining the topography of the adjacent bottom, and correcting errors of charts now in use.

Until the beginning of the 16th century navigation was rude, uncertain, and extremely dangerous owing partly to ignorance of coast lines, depths and currents. Though conditions of navigation continued to improve with progress in geography, there was no united effort to supply reliable charts and sailing directions, or other aids to navigation, till the beginning of the 19th century. Prior to the founding of the English hydrographic office in 1795, navigators were dependent upon individual enterprise for their charts and sailing directions. In 1815 at the close of England's war, interest in both trade and science was revived and the need of careful coast surveys throughout the world became generally recognized by various governments. England was the leader in this movement to make the sea safe for navigation, and undertook to survey the coasts in various widely separated regions where the local inhabitants were not equal to the task. At the suggestion of President Jefferson, in 1807 the U. S. Coast Survey was organized. Some years later the scope of the organization was enlarged, and the name was changed to the U. S. Coast and Geodetic Survey. Following England's lead, France, the pioneer in geodetic surveying, Russia and the Scandinavian countries engaged in the coast survey movement. This coöperative effort of the nations to provide the navigator with adequate information, and the marvelous improvements in nautical instruments, especially the compass, and

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chronometer, inaugurated a new era in the science and art of navigation.

As would be expected, knowledge of the floor of the Pacific was obtained much later and much more slowly than that of the coasts. Up to the middle of the 19th century the erroneous opinion prevailed that the Pacific was a comparatively shallow ocean. During the latter half of the past century, when satisfactory methods of deep sea sounding were devised, several lines of soundings were made in the Pacific, partly in the interests of pure science, and partly to supply information needed in order to select routes of the telegraph cables. These soundings dispelled the illusion as to the comparative shallowness of the Pacific. However, the deep soundings made up to the present time in the Pacific are far from uniformly distributed and are decidedly too few in number for making a satisfactory contour map of the ocean basin. There are immense areas, millions of square miles in extent where no soundings have been made. The depth of a region of 12,000,000 square miles, or nearly twice the area of North America, between the Polynesian Islands and the American coast from Mexico to Chili, was known only in a very general way from observation of the velocity of sea-waves caused by earthquakes, till 1855 when a few soundings were made by the Italian vessel *Vettor Pisani*. One important result of sounding the Pacific is that it contains many deep chasms or "deeps", the deepest of which are found nearest to coasts containing the highest mountains. The greatest recorded depth is 5348 fathoms, just east of the Island of Mindanao, of the Philippine archipelago. Also evidence is accumulating that the regions of great heights, adjacent to great depths are under enormous stresses closely related to volcanic and seismic phenomena. Thus a more complete knowledge of the ocean depths would contribute much to some of the fundamental problems of geology.

PRESENT KNOWLEDGE OF PACIFIC OCEANOGRAPHY

Now let us consider some of the major results of surveys and soundings relative to the Pacific. Regarding 40° S. as its southern limit, the area of the Pacific is about 55 million square miles or nearly twice as great as that of the next largest ocean, the Atlantic; and seven times that of the continent of North America. Its mean depth is about 2.5 miles and the volume of water, 140 million cubic miles or six times that of all the land

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above sea level. It extends from latitude 40 degrees on the south to about 67 degrees on the north, a distance of 6500 miles, is 10,000 miles broad at the equator and exceeds the area of the whole land surface of the globe. The coast line of the Pacific Ocean is about 40,000 miles in length, which is much less than that of the Atlantic. Also the drainage area of the Pacific is scarcely half that of the Atlantic.

For descriptive purposes it is convenient to divide the Pacific into two parts by a line through Hawaii and Tahiti, about 155° West longitude. The eastern half is characterized by comparative uniformity in depth to within a small distance from land. There are very few islands and the coast is rugged, barren and mountainous. The western half is in complete contrast. The coast is comparatively low and fertile, and is deeply indented with gulfs and partially enclosed seas. Archipelagoes and numerous widely scattered islands rise above the uneven bottom whose depth averages about the same as the eastern half. Another character differentiating the western from the eastern portion is the great barrier reef 1,000 miles in length off the east coast of Australia. The apparently greater uniformity of depth of the Pacific in comparison to the Atlantic may be due in part to the fact that the Atlantic, owing to its smaller area and greater commercial importance, has been much more thoroughly surveyed than the Pacific.

Along with discoveries and investigations pertaining to the continents, islands, coasts and ocean bottom, considerable attention has been directed to the ocean itself. The physical properties of ocean water especially its motion, temperature, and density were first considered, and later, attention was directed to its chemical composition, its alkalinity and acidity, and the amount of various gasses in solution. There is no property of the sea more obvious than its motion as indcated by waves, tides and currents especially near shore. The horizontal flow, called a current, stream or drift, although not in general as apparent especially when far from land, is just as characteristic as the more obvious motions. The use of satisfactory methods of measuring currents has been greatly limited. We are mainly dependent for our knowledge of surface currents on the records of deviations of the actual courses of ships from their apparent courses indicated by compass readings and distances moved with respect to the water. Such knowledge has

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been supplemented by records of the tracks of drift bottles, wrecks, and natural floating objects, and by inferences from the distribution of temperature and salinity. The accumulated evidence up to the present time proves that oceanic circulation takes place in a vast system of courses traversing all the oceans. The general subject of oceanic circulation has engaged the attention of both practical navigators and scholars for centuries, and its importance in connection with other fields of inquiry, e.g., biology, geology, and meteorology, has long been recognized. Ocean currents have been of as great moment as air currents in the history of human progress. The dispersal of mankind and the gradual peopling of half the globe is regarded as due in great measure to transportation by ocean currents.

Measurements of ocean temperatures were begun much later than current, or tide observations. The thermometer was not invented till about the year 1600, and not until 1768, or nearly 50 years after the introduction of the improved Fahrenheit scale, were the ocean temperatures first measured. In 1772, or three years before Franklin's famous studies of the Gulf stream temperatures in the Atlantic, Pacific Ocean temperatures were first measured during one of Captain Cook's expeditions. In fact, this is the first purely scientific expedition on record. Accurate temperature observations below the surface were first made a few years later by H. B. de Saussure. He used the simple but very slow method of leaving an insulated thermometer at the desired depth for several hours, and immediately reading the temperature after raising the protected thermometer to the surface.

Franklin's gulf stream work gave rise to the general practice, followed by many navigators, of taking regular surface temperature observations as an aid to the study of currents, and during the latter half of the nineteenth century several nations supplied vessels especially equipped for carrying on scientific explorations. The scientists on these expeditions were engaged in measuring temperatures and densities at various depths, as well as in making soundings and collections of marine life. Also through the efforts of such leaders as Humboldt and Rennel in compiling, and studying records of various scattered observations of temperature, currents, and meteorological phenomena available in the first half of the 19th century, preliminary ideas regarding the general characteristics of the corre-

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sponding ocean and atmospheric phenomena were obtained. And along with the organized efforts of various governments for carrying on coast surveys, there was a more systematic collection by navigators of data on currents, temperature, winds and barometric pressures. In 1853, through the influence of Lieut. M. F. Maury of the U. S. Navy, a uniform system for making and recording ocean and atmospheric observations at sea was devised, and is still in use with only slight modifications. As such observations accumulate, they yield valuable information to the navigator regarding expected deviations from the course apparently sailed, and they form the basis of methods of foretelling and avoiding storms.

From a study of Maury's sailing charts, which appeared over a half century ago, and indicated the average conditions of wind and weather, marine interests soon found how to materially shorten the duration of voyages. Such marine data were perhaps more important in choosing the most favorable route between ports, when the world's commerce was carried mainly in sailing vessels. But it must be remembered that a large portion of ocean freight is now carried by tramp steamers of low power, sailing vessels and auxiliary schooners are widely used in coasting trade, and even the high powered steamers can be more economically operated by taking expected winds and currents into account. Thus, while all mariners are especially interested in the location and movement of storms and deviations from the courses apparently sailed, as indicated by log and compass, the problem of economical trade routes in which winds, temperatures and currents are important factors demands attention today, and not only safety, but economy in modern navigation can be increased by learning more about the ocean and by applying such knowledge.

The epoch making voyage of H.M.S. *Challenger* in 1872-76 marked the end of the older order of investigation, and the beginning of modern oceanography as a precise science. One of the basic undertakings of the *Challenger* expedition was the careful chemical analysis of many samples of sea water, from widely distributed positions in the larger ocean areas. This investigation led to the important conclusion that in general the proportion of the different substances remains nearly constant in the ocean, though the absolute amount, as indicated by the specific gravity or density of the water, varies materially.

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The preliminary investigations already made in the Pacific and elsewhere, demonstrate that an outstanding feature of any property, physical or chemical, of water in the ocean is its variability with respect to time at a given place. The condition of the ocean is an index of the actions of diverse causes varying in intensity. There is a continual tendency of the ocean to approach a condition of physical and chemical equilibrium, but owing to the varying nature of the influences constantly at work, adjustment to them is never complete. Therefore, sufficient continuity of observations both in time and space must characterize any thorough investigation of the ocean. It seems as if the opportunities are nearly passed for such spectacular achievements as discovering the region of greatest depth, being the first to sight an unchartered island, or revealing, by making a few observations, some fundamental fact, such as, the presence of water near its freezing temperature, even under the equator. Future progress will probably depend upon a vast amount of routine work, involving repeated observations of the same kind, using standard methods, accompanied by appropriate improvements in accuracy and technique. Without such data we cannot hope to fulfill the object of the science of physical oceanography, which, according to the French oceanographer, Thoulet, is "the application to the natural phenomena of the sea, the precise methods of the exact sciences, mathematics, mechanics, physics and chemistry."

The oceanographic problems of the future will be concerned largely with the distribution of physical and chemical properties and their interrelations. Owing to oceanic circulation, water having a certain temperature, salinity, etc., is continually moving into regions where local conditions tend to produce different magnitudes of these quantities, therefore oceanic circulation must be a central feature in all problems of distribution. The physics or chemistry of the ocean is evidently very different from the physics or chemistry of small samples of ocean water in a state of equilibrium. Thus, the treatment of oceanographic problems demands the coöperative efforts of many investigators in various fields of science using standardized methods of making observations. The nearest approach to observations in the Pacific sufficiently numerous and continuous to supply the basis for sound generalizations, relative to the ocean as a whole, is found in the numerous records in the log books of navy and commercial ships. The government meteorological charts of sur-

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face temperatures and currents are compiled largely from reports of navigators of such ships.

Our knowledge of the properties of water at intermediate depths of the Pacific is based on very meager evidence. In 1910, after the scientific deep sea expedition of the German steamer *Valdivia*, in the Atlantic and Indian Oceans, elaborate charts of the temperature conditions of these oceans were worked out by Gerhart Schott. This oceanographer concluded that it would be highly desirable to prepare similar charts for the Pacific, but after examining all available data found less than 700 lines of temperatures taken from the surface to the bottom. Moreover these were far from uniformly distributed. Thus, in attempting to draw the isotherms for various depths, zero, 100 meters, 200 meters, etc., he was guided by less than one vertical line of observation for every 50,000 square miles. Such deficient data may serve as a basis for determining dominant characteristics of certain temperature distributions not materially affected by changes of season. They may be of value in indicating certain regions where intensive observations would be of special interest.

Now I wish to call your attention to some of the salient features of the conclusions relative to the water of the Pacific and its overlying atmosphere. The phenomena of atmospheric and oceanic circulation constitute portions of a vast terrestrial mechanism driven by radient energy from the sun. The varying intensity of this radiation, the distribution of land and water, and the rate of turning of the earth on its axis determine the character of the circulation. And the distribution throughout the ocean, of physical and chemical properties such as temperature and salinity or saltness affords a valuable though indirect method of investigating ocean currents. Direct measurements of winds and atmospheric pressures provided by marine observers form the basis for our present knowledge of atmospheric circulation, or wind systems. And, on account of their accessibility, the lower levels of the atmosphere, and the upper surface or layer of the oceans are the regions best known. The compilation of many thousands of atmospheric and ocean observations in this area of contact of the atmosphere and hydrosphere leads to certain prevailing phenomena which make up a simple and well defined scheme, subject to important seasonal variations. In the North Pacific are two "centers of action." One is the area of high pressure whose center is at the latitude of

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San Francisco; and oscillates about a position half way between San Francisco and Hawaii. The winds blow outward from the high pressure area, along spiral paths continually turning to the right, thus producing a vast eddy with a clockwise motion. In the South Pacific conditions are similar except that the motion is counter clockwise. The deflection of these air currents agrees in both cases with what would be expected from the pressure changes and the effect of the earth's rotation. These two circulations combine to produce the well-known trade winds blowing from east to west in the equatorial regions.

In the northern winter season a low pressure area called the Aleutian low develops at about 50° North latitude, a counter clockwise motion of air about this center and bending toward it would be expected, and observations confirm this conclusion. In the northern summer this "low" weakens and at times even disappears while the "high" of temperate latitudes is most intense. In their essential features the surface currents of the ocean follow much the same courses as the winds which drive them, but are in general more stable. This great system of ocean currents corresponds to the fly-wheel of the terrestrial machine. In the middle of the equatorial current a little north of the equator, and corresponding to the zone of calms is the equatorial counter current arising indirectly from the impinging of the main current on land masses to the west, and attaining its maximum velocity in summer.

Also the great equatorial current flowing westward with a velocity of about one mile an hour, and having a breadth of some 3000 miles gives rise to two warm backwater streams, one deflected to the south and one to the north, by the western land barriers. The latter, or Japan stream continues in a vast curve to the east, where, with diminished velocity, in the neighborhood of the State of Oregon, it divides into two branches, the smaller one flowing north and west along the Alaskan coast, the larger flowing south-west at a fraction of a mile per hour, and finally completing in the tropics the circuit of some 16,000 miles. Broadening to the west from Oregon, south as far as Magdalena bay in Lower California is the cold California current, believed to be supplied by the upwelling of cold bottom water all along the coast between these places. The main features of this North Pacific circulation are repeated in the South Pacific, but with a counter clockwise motion, and an uninter-

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rupted flow to the east at its southern border. The cold portion of the current flowing north along the west coast of South America is called the Humboldt or Peru current and is colder than neighboring waters by about 20° F.

The Equatorial circulation gives rise to a broad warm water area extending from 20° north to 20° south latitude at its western boundary and diminishing toward the east to less than 20° in width. This warm area includes nearly all of the coral producing regions of the Pacific.

The great zones of rapid evaporation in the trade wind areas on both sides of the equator correspond, as would be expected, to regions of high salinity. From these zones an enormous quantity of water is removed and carried as vapor to be precipitated on the Polar regions, both North and South, and on continental areas as well. To replace the water thus removed, the cold water, especially of the Antarctic, to which the Pacific opens freely, descends and flows very slowly toward the equator and upward. This cold bottom water also appears to be the source of the two cold surface currents already noted. Thus the bottom circulation, which is known only indirectly by inference, appears to be quite different from the better known surface circulation. The general tendency is toward an equalization of temperature extremes, and an aeration of the whole water mass.

While something is known about certain branch currents resulting from the intricacies of topographical features, and we have a general idea of the changes in circulation and temperatures from winter to summer, but little has been done toward gaining a detailed knowledge even in small inshore areas favorably situated.

In conclusion, it is of interest to us that the International Council for the Study of the Sea, organized in 1901, by representatives of leading European nations, has now resumed its activity, temporarily interrupted by the war. Two delegates each, from Great Britain, France, Belgium, Holland, Denmark, Sweden, Norway and Finland met in London from March 2-6, 1920, adopted an extensive program of exploration and study, and arranged to hold their next meeting in Copenhagen in 1921. In planning their program of work they were guided by the following general object: "The demarcation of the different water-strata according to their geographical distribution, their depths, their temperature, salinity, gas-content, plankton, and currents, in order to discover the fundamental principles

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that govern the distribution of marine animals useful to man, and also for weather-forecasts over extended periods in the interests of agriculture."

No such coöperative plan has been followed in the investigation of the Pacific Ocean. But the encouraging results of the European plan, involving observations limited mainly to the Northeastern Atlantic and its neighboring seas and gulfs suggests something of the reward to be expected from a suitable program of oceanographic work in the Pacific. Let us try to profit by the example of European nations whose richer and older experience has demonstrated the importance of a careful and thorough knowledge of the oceans.

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HYDROGRAPHIC ASPECTS OF OCEAN CURRENTS

By G. W. Littlehales

In response to the request of the committee on Program the following contribution is presented.

The seat of this Conference is in a realm of unsurpassed promise for the fruits of scientific investigation. The emporium of Honolulu stands in a central place in an expanse of ocean whose vast area exceeds by 10,000,000 square miles the total land surface of the globe, and whose cubical content is estimated to be seven-fold greater than the bulk of all the land above sea level. The indications are that throughout nine-tenths of its expanse the depths are greater than one mile, and throughout three-fourths of its expanse the depths are greater than two miles. Many high mountains rise from the bottom of the great oceanic basin of the Pacific, often culminating in emergence above the surface of the waters; and many deep depressions sink beneath the general level of its floor, especially in the western part: the highest mountains upon the islands of the ocean are those which rise upon the Hawaiian islands, and it contains the greatest depression hitherto discovered in the earth's crust, marked by a sounding of 5352 fathoms near the island of Mindanao—a depth so profound that if the highest elevation in the world above sea level were set down within it, the summit would yet be 3000 feet beneath the surface of the sea.

The presence of so great a volume of a substance having the highest known capacity for heat—which may be gauged by the statement that the specific heat of sea water is about thirty times that of mercury—must constitute the Pacific Ocean a dominant factor in terrestrial physics, exercising a governing influence through its circulation upon heat transference and upon climate and the development of vegetation, and, by the enginery of its variation of physical condition from season to season and year to year, promising, when it comes to be understood, to enhance all those wealth-producing sources which operate in seasonal cycles.

The former and present role of the ocean in the history of the earth and in its economy has forged bonds of kinship between oceanography and many other branches of science, because oceanographical investigation presents a field in which the

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interests of the cognate sciences conspire to induce cooperation.

It is in the aerial ocean overlaying the marine ocean that the prime mover in oceanic circulation is found. Operating around regions of barometric maxima in the eastern part of the temperate zone of the north Pacific and south Pacific respectively, where action-centers exist through the accumulation of more than the average amount of the earth's atmosphere, the winds induce surface currents in the ocean moving in a clockwise circuit in the north Pacific and in an anti-clockwise circuit in the south Pacific with modifications brought about by the influence of atmospheric centers of action where there is less than the average amount of the earth's atmosphere and yet others where there is alternately less or more of the earth's atmosphere. In the tradewind regions evaporation is very great and hence the salinity of the surface waters is high, but as the temperature is also high in these regions, the highly saline water remains at the surface during its westward drift in the tropical region on both sides of the equator and thence poleward in the western part both of the north Pacific and south Pacific until by reduction in temperature, the density becomes greater than that of the surrounding waters. The systematically varying distribution of salinity and temperature giving rise to a systematic distribution of density or heaviness of the waters, is one of the basic factors in the sub-surface or inner circulation of the ocean, causing a systematic descent from the surface of the heavier waters which characterize the polar borders of the temperate zones, and a slow movement thence of the deeper waters, entirely distinct from the oscillations of the mass of the ocean set up by seiches and tides, both toward the equator and toward the pole in the south Pacific and toward the equator in the north Pacific, where ascending currents rise from the depths. The characteristics of this system of circulation may be interpreted by profiles showing the distribution of temperature in the depths and confirmed by profiles showing the distribution of oxygen in the depths. In the former, the isothermal lines show a pronounced downward trend in the polar borders of the temperate zones and a pronounced upward trend in the equatorial regions; and in the latter it is evident that the waters in the depths of the ocean in the equatorial regions have been much longer out of contact with the atmosphere than the waters of

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the temperate latitudes which, descending from recent contact with the atmosphere, contain by absorption about three times as much oxygen as the deep equatorial waters which have ascended from the depths at the close of the long circuit of the bottom waters toward the equator.

These massive movements are in striking contrast to the relatively rapid rate of motion of the surface currents impelled for the main part in general accord with the anti-cyclonic circuit of the winds, which, in their direct and indirect effects taken in conjunction with the configuration of the continents, constitute the prime agency in originating and maintaining the circulation of the ocean.

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INSHORE CURRENTS

By J. T. Watkins

(Abstract prepared by the author.)

In connection with the previous statements concerning submarine relief, general circulation and other phenomena of the ocean in their broader aspects, attention is invited to the marked changes in character which such phenomena undergo as we leave oceanic depths and approach the shore.

In the coastal waters the bottom relief often shows the same complex character as the neighboring topography. Here also the horizontal and vertical movements of the water are most variable and no less complex than the associated submarine relief. The same is true of the distribution of temperature and salinity. In these shoaler waters terrestrial magnetism exhibits many of the marked local variations and disturbances which are characteristic of the land, rather then the more gradual changes from point to point over ocean areas.

In view of this greater complexity of phenomena encountered and the more detailed data required in a survey of these important waters extending inshore from the 1000-fathom curve, it is at once apparent that the work should be undertaken as soon as possible and completed as quickly as practicable; and not only on account of the great basic scientific value of the results to oceanography and related subjects, but because it is indespensable to the safe and economical navigation of these important waters and will contribute data useful to various other maritime interests.

The marked regularity and frequent occurrence of curves in the shoreline noted in the vicinity of Cape Cod Bay, at Cape Canaveral and in other localities, prompted an examination of the more striking examples with a view to ascertaining the nature of such forms and their cause.

Many of these features were studied on survey field sheets of comparatively large scale and of a high degree of precision, and the conclusion was reached that the curve is apparently parabolic and of the form $y^2=2px$.

It seems that this alignment of the shore lines is the form of equilibrium or stability assumed by the resisting material of the shore in opposing the activity of the mean resultant of the

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inshore waves and currents operating through erosion, transportation and deposition.

This type of shore line is found in some rivers where the material of the banks and the velocity of the current favor its development; the lower Mississippi River is an example.

The alignment of the 100-fathom curve in parts of the Straits of Florida, the south shore of the estuary of the St. Lawrence and also the axis of the Aleutian Chain of islands were possibly influenced in this manner.

If this form does develop the maximum resistance of the shore material and reduces the effectiveness of waves and currents to a minimum, then it is not only an interesting physiographic feature, but may have controlling influence upon the design of dredged channels, training walls, jetties, breakwaters and similar works, as the alignment adopted for them has an important bearing upon their stability and efficiency.

It is also evident that pipes, flumes and other artificial channels, in which the motion of the contained liquid undergoes change of direction, may give better results if the changes of direction are made along a parabola instead of the usual circle.

The object of these speculative notes is to suggest the desirability of further inquiry into the matter.

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OCEAN CURRENTS AND ISOSTASY

By William Bowie

(Remarks in response to a call from the Chairman.)

The investigations in the subject of isostasy have led to the definite conclusion that land masses which appear above the surface of the oceans have less dense material in the outer portion of the earth's material under them than exist under the ocean areas.

Isostasy cannot explain how this condition came about; whether oceans have always existed in their present positions and whether continents have always existed where we now find them are questions that the geodesists do not consider.

As the continents are eroded, the isostatic adjustment from the areas of deposition to the areas of erosion should result in the land areas becoming gradually lower. This is due to the fact that as a certain volume of light material is eroded from the surface an equal mass of somewhat heavier material is carried into the column under the area of erosion. We can readily see that the volumes being different, the surface should become lower in elevation.

That there have been enormous changes in elevation is not to be doubted. These changes come about from some other cause than merely isostatic adjustment. If we have had these great changes which have been observed in continental areas, then it is possible that some decided changes in elevation may have taken place within the ocean areas. If such changes have taken place then undoubtedly changes in the strength and direction of ocean currents would have resulted.

The geodetic studies involving the theory of isostasy do not throw any light whatever on the constancy of the oceans and of the continents. Of course, if only the isostatic adjustment were operating in the outer portion of the earth, then we should expect the oceans and continents to remain practically unchanged but, as stated above, it is found that great changes in elevation have occurred which canot be accounted for on the theory of isostasy.

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OCEAN CURRENTS AND GEOLOGICAL CHANGE

By Henry S. Washington

(Remarks in response to a call from the Chairman.)

It is generally assumed that the earth cooled from a more or less molten condition giving a solid crust and getting its water from the condensation of the primitive atmosphere. Certain general lines of fracture appeared in this crust resulting in forming raised areas making the shores of oceans. The general positions of oceans and continents have remained the same with various risings and sinkings resulting in variations in relative areas, depths and elevations. We have reason to think that the continental masses and ocean areas date from the dawn of geological history. As evidence we find the oldest rocks in the centers of continental masses, for example, around Hudson Bay. We find that the deposits are all from relatively shallow water, say from 100 to 200 fathoms. No evidence of abysmal deposits are found in the interiors of continental masses. The rocks on the ocean floors are relatively heavy, of continents, relatively light.

Therefore the ocean currents have been essentially the same, with more or less variation due to supposed risings and fallings in parts of the earth's surface. This does not affect the deeper areas.

The bottom of the ocean is but little known. It is hoped that the Conference will emphasize the importance of the study and exploration of the Pacific bottom. The hetrographical character of the sea bottom deposits is important. The *Challenger* found these to be uniform after the first few miles from shore, consisting, in the deepest parts, of red clay of unknown depth and supporting no life. Borings should be taken even into the rocky floor beneath. Chemical analysis indicates this red clay to be of volcanic origin.

The iceberg-borne blocks of rock found on the sea bottom might furnish valuable evidence as to the ocean currents. A study of the spherical bodies from meteors known as chondrules found in oceanic deposits would also be valuable. There may also be found some of the yellowish white glass stones, (moldarites, australites, etc.) now found in a few localities where there is no volcanic activity, which are supposed to be meteoric, and if found on the ocean floor these might give valuable data on their meteoric origin.

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OCEAN CURRENTS IN RELATION TO ORGANISMS

OCEAN CURRENTS, THE PRIME FACTOR IN THE DISTRIBUTION OF MARINE MOLLUSKS ON THE WEST COAST OF AMERICA

By Paul Bartsch

In this paper I have considered all the available data relating to the distribution of the recent west American species of the family Pyramidellidae, described in Bulletin 68 of the United States National Museum, and the additional forms, described in the supplemental papers published in the Proceedings of the United States National Museum, volume 42, page 261, 1912, the Nautilus, volume 30, number 7, page 73, November, 1916, and the Proceedings of the Biological Society of Washington, volume 31, page 81, June 29, 1918. There have also been included here notes on specimens from the west coast of America, which have been determined for various institutions and individuals since the publication of these papers.

In the preparation of the present paper a card was prepared for each species, on which has been noted the number of specimens examined, the locality from which they were obtained, depth in fathoms, bottom temperature, character of bottom salinity and disposition of material, the last subdivided into two columns, one citing the catalogue number, the other the collection in which the material occurs.

These specific cards fall readily into a series of zoogeographic divisions, which in turn can easily be grouped to correspond with the great faunal provinces outlined by S. P. Woodward, Manual of Mollusca, London, 1851-1856, pages 355 and 372 to 377, and later more fully discussed by Dr. Dall in "Fur Seals and Fur Seal Islands of the North Pacific," part 3, 1899, page 539, and in the Proceedings of the United States National Museum, volume 37, 1909, pages 185 to 191.

My paper "A Zoogeographic Study based on the Pyramidellid Mollusks of the West Coast of America," Proceedings of the United States National Museum, volume 42, pages 297-346, suggests a slight rearrangement of the subdivision (faunal

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areas) which the larger provinces have been held to contain in the past. Here I have retained five primary provinces, using for them the terms Arctic, North Temperate, Tropic, South Temperate, and Antarctic.

The Arctic province includes the Arctic in the restricted sense and the Aleutic of the present paper. In the Arctic in the restricted sense there are 4 species belonging 2 each to the subgenera Evalea and Amaura. In the Aleutic these two subgenera are found containing 17 out of the 23 species peculiar to it, the remainder comprising a single species of Menestho, 3 of Strioturbonilla, and 2 of Pyrgolampros, the last named subgenus being practically confined to the North Temperate province which harbors 27 out of 30 known species.

The North Temperate province, embraces the Oregonic and Californic faunal areas. The leading feature in this province is the subgenus Pyrgolampros, only 1 species of which is known in the Tropic province while 2 only are found in the Arctic. The subgenus Mormula is also quite characteristic; 4 out of 16 species are found in the Tropic, and none are known from the Arctic province. The subgenus Ivara is entirely confined to this province, and Careliopsis and Salassiella are known from the Californic faunal area only. Evalea finds its greatest development here, being represented by 52 of the 68 species known from the entire west coast.

The Tropic province embraces the Mazatlanic, the Panamic and Galapaganic. In this we find the following subgenera peculiar to the region, Pyramidella, Pharcidella, Ugartea, Asmunda, Lysacme, Salassia, Pyrgulina and Haldra. The rather large subgenus Amaura is entirely unrepresented and Pyrgolampros has but a single representative.

The South Temperate province, has so far revealed only 4 representatives, 3 of which belong to the subgenus Pyrgiscus which ranges over the North Temperate and also the Tropic, and one of the subgenus Menestho, which has an equally extensive distribution.

The Antarctic Pyramidellid fauna is unknown at present, but judging from the currents, one notes that 2 faunal areas are indicated in the Antarctic province; one, the Magellanic, corresponding to the Aleutic of the northern hemisphere covering the region between Chiloe Island and the Strait of Magellan, the other, the Antarctic, in the restricted sense, corres-

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ponding to the Arctic, in the restricted sense of the northern hemisphere, covering the South Shetlands and the territory to the south of them.

The present study marks well the various subdivisions of the larger provinces into which the continental shelf fauna of the west coast of America is divided.

They may be defined as follows:

1. ARCTIC. This extends from the summer limit south to the winter limit of the pack ice, that is, from the Sea-Horse Islands south to Hagemeister Island. This region is characterized by 4 species belonging to 2 subgenera. (See first column of summary.)

2. ALEUTIC. This embraces the Aleutian Islands, the Alaskan Peninsula, and the main coast of Alaska with their adjacent islands south of Sitka, and probably the inland straits south to Dixon Entrance. This region is characterized by 23 species belonging to 5 subgenera; two additional species are common to this and the next area. (See second column of summary.)

3. OREGONIC. This faunal area extends from Sitka, Alaska, south to Point Conception, California, and probably south on the outside of San Miguel, Santa Rosa and San Nicholas, and San Clemente Islands. It is characterized by 74 species belonging to 14 subgenera. Eleven additional species extend over this and the next area. (See third column of summary.)

4. CALIFORNIC. This extends from Point Conception, California, south to Cape St. Lucas, Lower California. It is characterized by 173 species belonging to 27 subgenera. Two species are common to this and the next area. (See fourth column of summary.)

5. MAZATLANIC. This extends from Cape St. Lucas, south to Acajutla, Guatemala. It is characterized by 101 species belonging to 29 subgenera. No species are common to this and the next area. (See fifth column of summary.)

6. PANAMIC. This area extends from Acajutla south perhaps to Aguja Point, Peru. It is characterized by 47 species belonging to 19 subgenera. (See sixth column of summary.)

7. GALAPAGANIC. The fauna of these islands, though small, is absolutely distinct and denotes a separate area. It consists of 5 species belonging to 5 subgenera. (See seventh column of summary.)

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The Pyramidellid material from the west coast of South America south to Aguja Point, Peru, is exceedingly scant, too much so to permit of any definite mapping of faunal areas based upon this group alone, but if we apply the same factors which are found to hold in the northern hemisphere, we can say that one area, the Peruvic (8), extends from Point Aguja, Peru, south to Chiloe Island to the Strait of Magellan, and a third, the Antarctic (10), probably covering the South Shetlands, extending from there southwards. This is supported by the meager evidence furnished by the representatives of the other groups of mollusks so far studied.

The faunal areas here listed show a remarkable coincidence with the ocean currents in the region under discussion, which demands consideration.

First of all it should be borne in mind that all the members of this family are free-swimming during their early stages, which renders them subject to being carried by the ocean currents. Their future success in life after passing the free-swimming stage depends upon finding a suitable habitat for their subsequent existence—a habitat which would embrace all the necessary conditions of topography, temperature, salinity, and food supply. It seems quite reasonable to suppose, and the insufficient data at hand indicate, that the coasts washed by the great ocean currents have in the main a corresponding uniformity of temperature, salinity, and food supply (plankton), the chief factors in the environment of marine animals. It therefore seems most reasonable to assume that it is due to the domination of these factors by the currents that we find the parallelism or coextensiveness of ocean currents and the faunal areas.

In the North Pacific we have the Kuro-Siwo or Japan current, which on reaching our coast splits, the north deflection sweeping the shores of Alaska and the Aleutian Islands, marking the Aleutic faunal area, while the south deflection sweeps southward off the coast of Washington, Oregon, and California as far as Point Conception, where the greater part is deflected seaward, probably sweeping the outside of San Miguel, Santa Rosa, San Nicholas, and San Clemente Islands thus outlining the Oregonic faunal area. Recent studies by Dr. George F. McEwen have shown that there is an upwelling of cold water along parts of California coast and also an inshore northward

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drift. It is to be hoped that extensive collection of marine organisms will be made. These collections should be provided with exact data to show their relation to drift and to currents. It seems not at all unlikely in the light of Dr. McEwen's study that we may have to consider a further subdivision of our faunal areas in this region.

A weak continuation of the main current passes southward along the coast of California from Point Conception to Cape St. Lucas, Lower California, where it is deflected seaward, thus covering the faunal area designated as Californic.

The equatorial current strikes the Central American coast about Acajutla and passes northward into the Gulf of California, turning westward at Cape St. Lucas. This maps the Mazatlantic faunal area.

The region between Acajutla and Point Aguja, Peru, appears to be free from any large ocean currents and represents the Panamic faunal area.

The South Pacific or Peruvian current strikes the South American shores about Chiloe Island, Chile, a part being deflected toward the Galapagos Islands. This may be considered as marking the Peruvic faunal area, though little is known of its Pyramidellid fauna.

Another part is deflected southward and sweeps the coast of South America from Chiloe Island to the Straits of Magellan. This maps the Magellanic faunal area.

The South Shetland Islands and the territory to the south may be considered as embracing the Antarctic faunal area in the restricted sense. These following tables are based upon the specific cards, showing the geographic range of each species. An "o" is used to denote its presence in a faunal area. When a species extends over more than one faunal area, the "o" will appear in all the columns covered by its range. Subspecies have been given the same rank as species in plotting these tables.

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SPECIES	Northern extreme range	Arctic	Aleutic	Oregonic	Californic	Mazatlanic	Panamic	Galapaganic	Peruvic	No. of spec.	Southern extreme range
Gen. PYRAMIDELLA											
Subg. Pyramidella											
bairdi		....	....	....	....	o	....	....	....	1	
Subg. Voluspa											
auricoma	Gulf California	....	....	....	....	o	....	....	....	3	Mazatlan
cerrosana		....	....	....	o	....	....	....	....	1	
										4	
Subg. Longchaeus											
mazatlanica	San Diego	....	....	....	o	o	....	....	....	5	Cape Tepoca
adamsi	Monterey	....	....	o	o	o	....	....	....	44	Gulf Cal.
bicolor		....	....	....	....	o	....	....	....	3	
mexicana	San Diego	....	....	....	o	....	....	....	....	2	Lower Cal.
magdalenensis		....	....	....	....	o	....	....	....	1	
conica		....	....	....	....	....	o	....	....	1	
lamellata		....	....	....	....	o	....	....	....	1	
										57	
Subg. Pharcidella											
hastata		....	....	....	....	o	....	....	....	5	
panamensis		....	....	....	....	....	o	....	....	2	
moffati		....	....	....	....	o	....	....	....	2	
achates	Gulf California	....	....	....	....	o	....	....	....	2	Mazatlan
		....	....	....	....	....	....	....	....	11	
Gen. TURBONILLA											
Subg. Turbonilla											
gilli	Catalina	....	....	....	o	....	....	....	....	5	San Diego
g. delmontensis		....	....	o	....			....	....	1	
centrota		....	....		....		o	....		1	

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ima							o			1	
diegensis	San Pedro				o					94	San Diego
acra					o					1	
lucana						o				1	
prolongata						o				1	
										105	
Subg. Ptycheulimella											
obsoleta						o				1	
abreojensis					o					1	
										2	
Subg. Chemnitzia											
hypolispa	Catalina Island				o					8	San Diego
gabbiana				o						1	
aepynota	San Pedro				o					19	S. Martin Id.
muricata						o				2	
santarosana	S. Rosa I.				o					12	San Diego
clarinda					o					8	
paramoea							o			1	
houseri								o		2	
aculeus							o			2	
muricatoides				o						8	
kelseyi	Santa Barbara				o					132	San Ignacio
raymondi	S. Rosa I.				o					24	San Diego
										219	
Subg. Strioturbonilla											
stephanogyra							o			1	
redondoensis						o				1	
dinora					o					4	
panamensis							o			6	
schmitti						o				3	
buttoni	S. Rosa I.				o					155	Pt. Abreojos
santamariana						o				1	
vancouverensis	Port Etches		o	o						119	Barkley Sd.
asser	Redondo				o					13	San Diego
mexicana						o				14	

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GEOGRAPHIC TABLES—Continued

SPECIES	Northern extreme range	Arctic	Aleutic	Oregonic	Californic	Mazatlanic	Panamic	Galapaganic	Peruvic	No. of spec.	Southern extreme range
attrita	Long Beach				o					46	
encella					o					1	
nicholsi						o				1	
bakeri					o					4	
torquata	Pt. Fermin				o					10	San Diego
stylina	Monterey			o	o					6	Coronado Id.
barkleyensis			o							29	
canadensis			o							4	
calvini						o				7	
carpenteri					o					3	
simpsoni	Redondo				o					42	San Diego
profundicola	Catalina Island				o					3	La Jolla
galianoi	Pacific Beach				o					13	Cape St. Lucas
humerosa	Catalina Island				o					3	San Diego
c-b-adamsi						o				13	
serrae	Barkley S.			o						39	Monterey
dracona					o					6	
aresta	S. Rosa I.				o					21	San Diego
pazana	Ceralvo I.					o				48	Lower Cal.
galapagensis								o		1	
undata						o				1	
affinis							o			1	
phanea						o				0	
imperialis							o			1	
smithsoni						o				2	
doredona						o				1	
gracilior							o			1	
montezuma						o				17	

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cookeana											
										651	
Subg. Pyrgolampros											
victoriana	Departure B.			0						18	Victoria
gibbosa						0				2	
ridgwayi					0					1	
valdezi	Barkley S.			0						3	Monterey
newcombei	Port Simpson			0						20	Victoria
taylori	Port Simpson			0						94	Barkley Sd.
talama				0						2	
lowei	San Pedro				0					17	San Diego
halibrecta					0					1	
pugetensis				0						9	
tremperi					0					1	
gouldi	S. Rosa I.				0					18	San Diego
aurantia	Departure Bay			0						12	
pedroana	San Pedro				0					11	Pt. Loma Lt.
halia	San Pedro				0					7	San Diego
lyalli				0						1	
berryi	Santa Cruz			0	0					4	Catalina Id.
alaskana	Port Althorp		0							21	Sitka Harbor
chocolata					0					1	
gloriosa					0					1	
painei	Rendondo				0					5	San Diego
macouni				0						3	
keepi	Long Beach				0					8	Catalina Id.
halistrepta					0					3	
pesa				0						2	
rinella				0						1	
lituyana				0						3	
oregonensis	Washington		0							3	
hannibali				0						3	
franciscana					0					41	
										316	
Subg. Pyrgiscus											
annettae									0	2	

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GEOGRAPHIC TABLES—Continued

SPECIES	Northern extreme range	Arctic	Aleutic	Oregonic	Californic	Mazatlanic	Panamic	Galapaganic	Peruvic	No. of spec.	Southern extreme range
gracillima		....	....	....	....	o	....	....	....	2	
vexativa	San Pedro	....	....	....	o	....	....	....	....	4	Pt. Loma
obesa		....	....	....	o	....	....	....	....	1	
favilla		....	....	....	....	....	o	....	....	1	
pequensis		....	....	....	o	....	....	....	....	1	
nuttingi	San Pedro	....	....	....	o	....	....	....	....	18	San Diego
lazaroensis		....	....	....	....	o	....	....	....	1	
mariana		....	....	....	....	o	....	....	....	1	
almejasensis		....	....	....	....	o	....	....	....	3	
callia		....	....	....	o	....	....	....	....	1	
tecalco		....	....	....	....	o	....	....	....	3	
superba		....	....	....	....	o	....	....	....	3	
pluto		....	....	....	o	....	....	....	....	1	
jewetti	San Pedro	....	....	....	o	....	....	....	....	71	Lower Cal.
signae		....	....	....	o	....	....	....	....	1	
striosa		....	....	....	....	....	o	....	....	1	
morchi	Redondo	....	....	....	o	....	....	....	....	13	San Diego
aragoni		....	....	o	....	....	....	....	....	1	
cabrilloi		....	....	....	....	o	....	....	....	1	
corsoensis		....	....	....	....	o	....	....	....	6	
recta	San Diego	....	....	....	o	....	....	....	....	2	
weldi		....	....	....	o	....	....	....	....	2	
ina		....	....	....	o	....	....	....	....	1	
nereia	San Pedro	....	....	....	o	....	....	....	....	2	San Diego
antestriata	Esteros B.	....	....	....	o	....	....	....	....	17	Zuninga
antemunda	S. Rosa I.	....	....	....	o	....	....	....	....	23	Catalina Id.
flavescens		....	....	....	....	o	....	....	....	1	
macbridei		....	....	....	....	o	....	....	....	1	
macra		....	....	....	o	....	....	....	....	6	

angusta	C. San Lucas					o				1	
tenuicula	Monterey			o	o					1425	Pt. Abreojos
callimene					o					1	
virgo					o					1	
marshalli						o				2	
canfieldi				o						1	
almo					o					4	
callipeplum							o			1	
dina							o			2	
shimeki								o		2	
sanctorum						o				25	
eucosmobasis	S. Luis Obispo				o					9	San Diego
halidoma						o				1	
auricoma	San Pedro				o					16	Scammon Lagoon
bartolomensis						o				1	
cortezi						o				3	
eva					o					1	
castanea	San Pedro				o					13	San Diego
dora					o					1	
castanella				o						1	
grippi					o					1	
indentata						o				1	
cora									o	1	
craticulata							o			3	
ceralva						o				2	
lepta						o				2	
histias						o				3	
subula							o			1	
wickhami					o					5	
lara						o				45	
cinctella							o			1	
adusta					o					1	
larunda						o				4	
ista					o					1	
lamna						o				2	
baegerti						o				1	
ulloa						o				1	
latifundia					o					2	

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GEOGRAPHIC TABLES—Continued

SPECIES	Northern extreme range	Arctic	Aleutic	Oregonic	Californic	Mazatlanic	Panamic	Galapaganic	Peruvic	No. of spec	Southern extreme range
haliplex					o					1	
										1781	
Subg. Mormula											
lordi	Sitka Harbor			o						18	Pt. Orchard
regina	S. Rosa I.				o					6	Catalina Id.
catalinensis					o					3	
eschscholtzi	Port Simpson			o						98	Barkley Sd.
tridentata	Monterey			o	o					52	San Diego
ambusta					o					4	
scammonensis					o					2	
major							o			1	
santosana					o					3	
pentalopha	San Pedro				o					64	Todos Santos
heterolopha	Ocean Beach				o					16	San Hipolito Pt.
ignacia					o					3	
sebastiani						o				1	
periscelida					o					3	
phaleros							o			1	
viscainoi						o				1	
										276	
Subg. Bartschella											
sedillina						o				12	
laminata	San Pedro				o					167	Pt. Abreojos
hipolitensis					o					3	
excolpa						o				1	
subangulata						o				1	
andrewsi							o			4	

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arata					o					1	
genilda							o			4	
										193	
Subg. Dunkeria											
monilifera						o				1	
cancellata						o				1	
festiva							o			1	
eucosmia						o				3	
swani					o					1	
paucilirata						o				1	
guilleni						o				1	
										9	
Subg. Cingulina											
urdeneta						o				47	
Subg. Ugartea											
juani						o				2	
Subg. Asmunda											
turrita							o			3	
Subg. Careliopsis											
stenogyra					o					2	
Gen. ODOSTOMIA											
Subg. Lysacme											
clausiliformis						o				1	
Subg. Salassiella											
laxa	Pacific Beach				o					4	Scammon Lagoon
richi					o					1	
										5	
Subg. Salassia											
tropidita							o			1	
scalariformis						o				1	
										2	
Subg. Besla											
convexa	Cacachitas					o				5	Mazatlan

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GEOGRAPHIC TABLES—Continued

SPECIES	Northern extreme range	Arctic	Aleutic	Oregonic	Californic	Mazatlanic	Panamic	Galapaganic	Peruvic	No. of spec.	Southern extreme range
excolpa		....	....	....	....	o	....	....	....	1	
callimorpha		....	....	....	o	....	....	....	....	1	
										7	
Subg. Chrysallida											
heterocincta		....	....	....	o	....	....	....	....	1	
reigeni		....	....	....	....	o	....	....	....	1	
zeteki		....	....	....	....	....	o	....	....	1	
inconspicua		....	....	....	....	....	o	....	....	1	
telescopium		....	....	....	....	o	....	....	....	3	
excelsa		....	....	....	....	....	o	....	....	1	
taravali		....	....	....	....	o	....	....	....	2	
acrybia		....	....	....	o	....	....	....	....	1	
communis		....	....	....	....	....	o	....	....	15	
torrita		....	....	....	....	o	....	....	....	5	
licina		....	....	....	o	....	....	....	....	2	
talama		....	....	....	o	....	....	....	....	4	
effusa	Mazatlan	....	....	....	....	o	....	....	....	2	Cape St. Lucas
paupercula		....	....	....	....	....	o	....	....	1	
clathratula		....	....	....	....	....	o	....	....	10	
ritteri	Catalina Island	....	....	....	o	....	....	....	....	28	San Diego
rinella		....	....	....	....	....	o	....	....	1	
eugena	San Pedro	....	....	....	o	....	....	....	....	10	San Hipolito Pt.
trachis		....	....	....	o	....	....	....	....	1	
lucca	Monterey	....	....	o	o	....	....	....	....	7	San Diego
clementina		....	....	....	o	....	....	....	....	1	
conisca		....	....	....	....	o	....	....	....	9	
oldroydi	San Pedro	....	....	....	o	....	....	....	....	3	Los Coronados I.
nodosa		....	....	....	....	o	....	....	....	2	
[illegible]		....	....	....	....	o	....	....	....	2	

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cincta	San Pedro				o					3	Pacific Beach
loomisi							o			9	
vicola					o					1	
astricta				o						1	
cooperi				o						1	
hipolitensis					o					1	
lapazana						o				3	
proxima							o			1	
tyleri							o			6	
scammonensis	Scammon Lag.				o					13	Pt. Abreojos
pulchra							o			1	
montereyensis	Del Monte			o						9	San Luis Obispo
pulcia	Monterey			o	o					152	San Pedro
virginalis	San Pedro				o					151	Pt. Abreojos
santamariensis						o				1	
defolinia							o			1	
d. contracta							o			1	
d. difficilis							o			1	
oregonensis	Q. Charlotte I.			o						12	Monterey
benthina						o				2	
promeces					o					1	
pulcherrima	San Pedro				o					2	San Diego
vincta					o					2	
fasciata						o				5	
helga	San Pedro				o					353	Coronado Id.
dicella					o					1	
thalia					o					1	
sanctorum	Todos Santos B.				o					7	San Hipolito Pt.
sapia					o					1	
rotundata						o				2	
deceptrix	S. Hipolito Pt.				o					8	Pt. Abreojos
										867	
Subg. Pyrgulina											
marginata							o			1	
Subg. Egila											
lacunata						o				7	
poppei					o					5	
										12	

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GEOGRAPHIC TABLES—Continued

Species	Northern extreme range	Arctic	Aleutic	Oregonic	Californic	Mazatlanic	Panamic	Galapaganic	Peruvic	No. of spec.	Southern extreme range
Subg. Haldra											
photis						o				2	
Subg. Ividella											
pedroana	San Pedro				o					99	Scammon Lagoon
navisa	San Pedro				o					87	Scammon Lagoon
n. delmontensis				o						1	
quinquecincta						o				1	
orariana							o			1	
										189	
Subg. Miralda											
hemphilli	San Pedro				o					6	Pt. Abreojos
armata						o				1	
exarata						o				1	
terebellum							o			1	
aepynota	San Pedro				o					68	Cape St. Lucas
galapagensis								o		1	
										78	
Subg. Ivara											
turricula	Monterey			o	o					80	Pt. Abreojos
Subg. Evalina											
americana	San Pedro				o					30	Coronado Id.
intermedia						o				1	
										31	
Subg. Iolaea											
amianta	Monterey B.			o	o					36	Pt. Abreojos
eucosmia	San Pedro				o					79	Pt. Abreojos
delicatula						o				1	
										116	
Subg. Menestho											

grammatospira		....	....	....	....	o	....	....	....	1	
phareida		....	....	o	....	....	....	....	....	11	
exara		....	....	o	....	....	....	....	....	1	
ziziphina		....	....	....	....	o	....	....	....	1	
recta		....	....	....	....	....	o	....	....	1	
gloriosa	San Diego	....	....	....	o	....	....	....	....	2	San Hipolito Pt.
amilda	San Diego	....	....	....	o	....	....	....	....	3	Round Island
callipyrga		....	....	....	....	....	o	....	....	1	
excisa		....	....	....	o	....	....	....	....	1	
farma		....	....	....	o	....	....	....	....	1	
enora		....	....	....	o	....	....	....	....	3	
chilensis		....	....	....	....	....	....	....	o	1	
fetella	Long Beach	....	....	....	o	....	....	....	....	320	San Ignacio Lag.
hypocurta		....	o	....	....	....	....	....	....	1	
aequisculpta		....	....	....	....	o	....	....	....	1	
harfordensis		....	....	o	....	....	....	....	....	1	
sublirulata		....	....	....	....	o	....	....	....	1	
										351	
Subg. Evalea											
nunivakensis		o	....	....	....	....	....	....	....	1	
killisnooensis		....	o	....	....	....	....	....	....	4	
youngi		....	....	o	....	....	....	....	....	3	
thea		....	....	....	o	....	....	....	....	1	
calliope		....	....	....	o	....	....	....	....	1	
calcarella		....	....	....	o	....	....	....	....	1	
tillamookensis		....	....	o	....	....	....	....	....	2	
esilda		....	....	....	o	....	....	....	....	1	
spreadboroughi		....	....	o	....	....	....	....	....	3	
vancouverensis		....	....	o	....	....	....	....	....	7	
aleutica	Bering Sea	....	o	....	....	....	....	....	....	16	Amaknak Id.
valeroi		....	....	....	....	o	....	....	....	8	
kadiakensis		....	o	....	....	....	....	....	....	2	
quadrae		....	....	o	....	....	....	....	....	44	
callimene		....	....	....	o	....	....	....	....	1	
herilda		....	....	....	o	....	....	....	....	1	
cypria		....	....	o	....	....	....	....	....	1	
hypatia		....	....	o	....	....	....	....	....	1	
tenuis		....	....	....	....	o	....	....	....	1	

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GEOGRAPHIC TABLES—Continued

SPECIES	Northern extreme range	Arctic	Aleutic	Oregonic	Californic	Mazatlanic	Panamic	Galapaganic	Peruvic	No. of spec.	Southern extreme range
valdezi	Barkley S.	....	....	o	....	....	....	....	....	15	Del Monte
nemo	San Pedro	....	....	....	o	....	....	....	....	53	
io	S. Barbara	....	....	....	o	....	....	....	....	13	
orcutti		....	....	....	o	....	....	....	....	1	
barkleyensis		....	....	o	....	....	....	....	....	5	
pratoma		....	....	....	o	....	....	....	....	37	
cookeana		....	....	o	....	....	....	....	....	2	
septentrionalis		....	o	....	....	....	....	....	....	3	
capitana	Kadiak I.	....	o	....	....	....	....	....	....	2	Unalaska
jewetti		....	....	....	o	....	....	....	....	2	
inflata		....	....	o	....	....	....	....	....	3	
columbiana	Vancouver I.	....	....	o	....	....	....	....	....	12	Port Townsend
unalaskensis		....	o	....	....	....	....	....	....	1	
willetti		....	o	....	....	....	....	....	....	11	
atossa		....	....	....	o	....	....	....	....	2	
obesa		....	....	....	o	....	....	....	....	11	
lucasana		....	....	....	....	o	....	....	....	1	
phanea		....	....	o	....	....	....	....	....	10	
phanella	San Pedro	....	....	....	o	....	....	....	....	3	San Diego
santarosana		....	....	....	o	....	....	....	....	1	
tenuisculpta	Barkley S.	....	....	o	o	....	....	....	....	501	Lower Cal.
angularis	Sitka Harbor	....	....	o	....	....	....	....	....	105	California
franciscana		....	....	o	....	....	....	....	....	8	
socorrensis		....	....	....	....	o	....	....	....	85	
baldridgae		....	....	....	o	....	....	....	....	2	
donilla	San Pedro	....	....	....	o	....	....	....	....	34	Todos Santis Bay
californica	Ocean Beach	....	....	....	o	....	....	....	....	6	S. Coronado I.
serilla	San Pedro	....	....	....	o	....	....	....	....	3	San Diego
tacomaensis		....	....	o	....	....	....	....	....	1	
amchitkana	Ellamar	....	o	o	....	....	....	....	....	12	Amchitka Id.

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clessini	[illegible]			[illegible]						[illegible]	[illegible]
minutissima	Admiralty I.			o						17	Sitka
raymondi	San Diego				o					11	Pt. Abreojos
gravida					o					2	
notilla					o					2	
movilla					o					2	
altina					o					8	
profundicola					o					3	
baranoffensis					o					10	
sitkaensis	Admiralty I.			o						5	Baranof Id.
hagemeisteri			o							2	
skidegatensis		o								1	
				o						17	
resina					o					1	
deliciosa	Barkley S.			o						24	Monterey
parella								o		1	
granadensis							o			1	
palmeri						o				2	
casandra				o						2	
										1242	
Subg. Amaura											
lastra	S. Catalina				o					7	Southern Cal.
kennerleyi	Nanaimo			o						48	Pt. Pinos Lt.
elsa			o							1	
beringi		o								1	
subglobosa					o					2	
satura				o						2	
helena					o					1	
pupiformis				o						1	
grippiana				o						1	
farallonensis					o					1	
sillana			o							1	
talpa	Mole Harbor			o						7	Sitka
krausei			o							3	
eldorana			o							2	
orcia	S. Rosa I.				o					7	San Diego
gouldi				o						1	
arctica	Arctic Ocean	o	o							26	Bristol Bay

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GEOGRAPHIC TABLES—Continued

SPECIES	Northern extreme range	Arctic	Aleutic	Oregonic	Californic	Mazatlanic	Panamic	Galapaganic	Peruvic	No. of spec.	Southern extreme range
avellana				o						5	
moratora				o						1	
pesa			o							4	
nota	S. Rosa I.				o					73	San Diego
iliuliukensis			o							12	
nuciformis				o						10	
canfieldi	Barkley S.			o	o					35	San Diego
subturrita	S. Rosa I.				o					45	Todos Santos B.
martensi			o							1	
										198	
Subg. Scalenostoma											
dotella						o				22	
babylonia					o					2	
rangii							o			1	
										25	
Subg. Heida											
kelseyi					o					2	
panamensis							o			2	
										4	
Subg. Odostomia											
farella					o					1	
dinella					o					1	
coronadoensis					o					3	
mammillata						o				1	
										6	

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SUMMARY

GENERA AND SUBGENERA	Arctic	Aleutic	Oregonic	Californic	Mazatlanic	Panamic	Galapaganic	Peruvic	Total No. of species of each subgenus
Gen. PYRAMIDELLA									
Pyramidella	......	......	......	......	1	......	......	......	1
Voluspa	......	......	......	1	1	......	......	......	2
Longchaeus	......	......	1 *1	3 *2	5	1	......	......	7
Phareidella	......	......	......	......	3	1	......	......	4
TOTAL	......	......	......	......	......	......	......	......	14
Gen. TURBONILLA									
Turbonilla	......	......	1	3	2	2	......	......	8
Ptycheulimella	......	......	......	1	1	......	......	......	2
Chemnitzia	......	......	2	6	1	2	1	......	12
Strioturbonilla	......	3 *1	3 *1	15	14	5	1	......	39
Pyrgolampros	......	2	14	14	1	......	......	......	31
Pyrgiscus	......	......	4	31	25	7	1	3	71
Mormula	......	......	3 *1	10	2	2	......	......	16
Bartschella	......	......	......	3	3	2	......	......	8
Dunkeria	......	......	......	1	5	1	......	......	7
Cingulina	......	......	......	......	1	......	......	......	1
Ugartea	......	......	......	......	1	......	......	......	1
Asmunda	......	......	......	......	......	1	......	......	1
Careliopsis	......	......	......	1	......	......	......	......	1
TOTAL	......	......	......	......	......	......	......	......	198

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SUMMARY—Continued

Genera and Subgenera	Arctic		Aleutic		Oregonic		Californic		Mazatlanic	Panamic	Galapaganic	Peruvic	Total No. of species of each subgenus
Total Forward	......		......		......		......		......	......	......	......	198
Gen. Odostomia													
Lysacme	......		......		......		......		1	......	......	......	1
Salassiella	......		......		......		2		......	......	......	......	2
Salassia	......		......		......		......		1	1	......	......	2
Besla	......		......		......		1		2	......	......	......	3
Chrysallida	......		......		6	*2	25		13	14	......	......	56
Pyrgulina	......		......		......		......		......	1	......	......	1
Egila	......		......		......		1		1	......	......	......	2
Haldra	......		......		......		......		1	......	......	......	1
Ividella	......		......		1		2		1	1	......	......	5
Miralda	......		......		......		2		2	1	1	......	6
Ivara	......		......		1	*1	1		......	......	......	......	1
Evalina	......		......		......		1		1	......	......	......	2
Iolaea	......		......		1	*1	2		1	......	......	......	3
Menestho	......		1		3		6		4	2	......	1	17
Evalea	2		9	*1	24	*1	28		5	1	1	......	68
Amaura	2	*1	8		10	*1	8		......	......	......	......	26
Scalenostoma	......		......		......		1		1	1	......	......	3
Heida	......		......		......		1		......	1	......	......	2
Odostomia	......		......		......		3		1	......	......	......	4
Total	......		......		......		......		......	......	......	......	205
Grand Total	4	*1	23	*2	74	*9	173	*2	101	47	5	4	417

* The numbers placed near the lines dividing the faunal columns indicate the number of species common to two adjacent areas. There was a total of 6694 specimens examined.

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INFLUENCE OF OCEAN CURRENTS ON THE DISTRIBUTION OF FISH

By H. F. Moore

(From the stenographic report of the Proceedings.)

I have been asked to speak on the significance of the relationship of ocean currents to fish. As Dr. Bartsch has pointed out, the distribution of organisms in general is dependent upon the currents and upon the salinity and temperature of the water. The organisms which are the objects of pursuit in the fisheries differ in no wise from these others. Every biologist knows these facts. Every fisherman knows that in order to make his catch he must cast his line or his net in waters which are congenial to the species which are his object.

While these are self-evident facts, it may not be without interest to point out just how the currents operate in their effects on the fisheries, just what takes place, how the fish are distributed, and how they are otherwise affected. The fishes of fresh water have eggs which I think invariably are heavier than the waters in which they are deposited. I can recall no species in which this is not the case. Of course if they had floating eggs deposited in the streams they would be carried out to sea and lost, or destroyed by coming into contact with the saline waters of the sea. On the contrary a very large number of marine fishes, the vast majority perhaps, and certainly the rare species of the fish which comprise the object of pursuit in the great fisheries of the world, deposit eggs which are lighter than the water and float. Cod, haddock, and all the fishes of that type, themselves living on the bottom, deposit eggs which come to the surface. Some of these fishes are themselves pelagic and the entire life of the organism is spent at or near the surface. On the other hand the distinctly bottom-dwelling fishes and even some of those which we have every reason to presume dwell on the bottom in very deep water, like the mackerel, also produce eggs which are lighter, float to the surface and stay there through their period of development.

When an egg is deposited it is usually more or less oval and does not ordinarily form a perfect sphere. After it is fertilized it absorbs water, swells up, and becomes spherical. Apparently the eggs have a higher saline content than that of the sea water in which they are deposited, and the process of

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the swelling of the egg is just an ordinary process of osmosis. The buoyancy of the egg depends of course on its own specific gravity and on the specific gravity of the water in which it lies and also on the viscosity of that water. As both the viscosity and the specific gravity are affected by the temperature, that factor in ocean investigation is a highly important one. When the eggs come to the surface they of course are subject to the movements of the ocean currents.

As the fish egg develops it loses water and becomes heavier. The same thing takes place as the fry develops, so that there is a tendency for both the egg and the fry to sink in the water as it is carried along, and eventually results in the young fish seeking the bottom and there taking up its permanent home.

On the coast of Iceland the spawning grounds of the cod are all at the northern end of the island. The important fisheries, however, are all on the southern and western portions and it has been found through recent investigations that these grounds on the south and west are entirely populated by the spawn from the northern part of the island.

On the coast of Normandy we have exactly the same conditions and it has been possible there to locate new fishing grounds for the cod by sowing eggs in the spawning grounds which are carried to distant banks 100 miles away where the larvae were produced.

The most remarkable example that we have of the carriage of fish and fish larvae through the agency of the currents is that of the common eel of Europe and the very closely related species on the American coast. These eels pass all their adult life in brackish water; nobody has ever seen them in fresh. For many years the spawning of eels was disputed, but recent investigations have shown that both species of eels spawn at sea in water two or three thousand fathoms deep. I do not know at what depth the eggs are cast, but I do know that they come to the surface. The day before I left Washington I had a visit from Dr. Smith of the Danish exploring vessel who gave me some account of the development of eels through his investigations. He has discovered that the center of the spawning of the European eels is in about latitude 27 degrees north and longitude 67 degrees west, much closer to the American coast than to the European coast. Now all of the millions of eels which go to the coast of Europe are hatched somewhere in

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that region, developed into little transparent, leaf-like leptocephali, very fragile looking things, and take this immense journey of, I suppose, 3000 miles, to the waters in which they mature. Dr. Smith has also found that our own American eel of the Atlantic coast spawns somewhere in that same region, probably a little to the south of the center of the other, but the two regions overlap.

The young eels produced in that region divide themselves according to the species, into two groups, one of which goes off in an easterly direction toward Europe, and the other approaches the American coast.

Now the significance of these things in the fisheries, this carriage of eggs and the young fish by the currents, must be self-evident. In connection with fish culture we cannot assume that because we deposit hatched eggs or larval fish on the spawning grounds that we are putting them in a region in which they will meet with favorable conditions. If we deposit eggs of different ages in such waters they are liable to be carried into areas unsuitable to them. Such actions must be conditioned on the recognition of these facts.

The currents also have an effect on the fisheries in carrying congenial water conditions to places remote from those in which they originate. On the Atlantic coast we have the Gulf Stream carrying its warm waters northward as far as Cape Cod, then reverting to the east. All along the edge of the Gulf Stream as far as Cape Hatteras, we have banks on which grow a large number of plants and animals which would normally inhabit a region farther south, and we have developed along there a series of fishery banks to which it is profitable for the fisherman to resort. It is probable that the existence of these banks is not due solely to the presence of warm waters, but also to the effect which is produced when two currents of different temperatures meet as they do in that region on the edge of the Gulf Stream. There is produced under such conditions a temperature situation which is liable to prove fatal to a certain large number of organisms in the two streams. The water becomes too warm for the organisms living in the cold stream, and too cool for those living in the warm stream. Consequently all along the edge of the point of contact of the streams of converging temperature conditions we have a constant drifting of organisms to the

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bottom where they provide food for the animals in the deep seas.

That very nice correlation between the temperatures and the animals inhabiting the waters and the sensitiveness of the organisms is not confined entirely to these smaller organisms. We have one classic case on the Atlantic Coast of North America where a large and powerful fish has been practically exterminated by some slight variation in the temperature conditions. That is the tile fish. It was discovered about 1879 about the time the Bureau of Fisheries began its systematic operations. A ship's master coming into New York reported that he had sailed for fifteen miles through a sea that was practically covered with dead fish. Afterwards we learned that instead of fifteen miles he had sailed sixty and was afraid to tell the story. Other ships' masters reported the same things. Investigation proved that the sea over an area of 125 miles long and 50 miles wide was covered with tile fish. It was estimated that 1,000,400,000 fish had been killed there. The commercial value of those fish was probably in the neighborhood of several million, so that the economic importance of that phenomena can be appreciated.

We had no particular data at the time to show just what had happened, but a few years later Professor Libby of Princeton made some investigations and found that the Gulf Stream was further off shore than it had been a few years before the tile fish were discovered. Further biological investigation determined that certain fauna that had been characteristic of the limit between the Gulf Stream and cold water in shore had practically disappeared along with the tile fish. The assumption that the changed temperature produced this cataclysm was confirmed later by the fact that the Gulf Stream was found to be undergoing a periodical movement, gradually coming nearer to the shore. About 1890 Professor Libby predicted that again in 1892 it would touch the bottom of the south coast of New England and would recreate the conditions which were favorable to the tile fish. About 1892 we found his prediction had come true. In the following year an investigation showed the tile fish had returned in small numbers.

This will, I think, illustrate the importance to the fisheries of having accurate information in regard to the phenomena of the sea. The significant feature of my remarks is, however, the

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fact that I have drawn all my illustrations from the Atlantic. I have done so because very little is known of similar relationships in the Pacific. The fisheries there are becoming more important and it is becoming increasingly necessary that we should extend our investigations to that great sea. The fishery investigations are going to depend primarily and fundamentally on the information which is to be given to us by the physiographers and oceanographers and I think all of those who are interested in the biological aspect of the subject should, as Dr. Bartsch has done, impress on physiographers and oceanographers the necessity of promptly undertaking very much more extensive and very much more detailed work than has heretofore been done.

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THE BIOLOGICAL ASPECTS OF OCEAN CURRENTS

By T. C. Frye

(From the stenographic report of the Proceedings.)

Coming from the region of Seattle and Puget Sound where the fisheries are one of the chief industries, naturally one's interest centers in the question of how the ocean currents of the Pacific and its shores are related to the problem of the production of more food for man. Of course we must look upon the Pacific and its shores as a great pasture of green plants which is the source of food either directly or indirectly (in the great majority of cases, indirectly) for whatever animals may be found there. In this great ocean pasture the most important source of food is the algae. The conditions for growth of these plants may be likened to the conditions for growth in an ordinary land pasture, where certain requirements are necessary.

One of the factors which control the growth of this layer of green plants near the surface of the ocean is temperature, which is a variable thing from the equator northward. Small plants and animals are quite sympathetic to changes of temperature. I did not know, however, large ones were so sympathetic as indicated by Dr. Moore's reference to the tile fish. Temperature is not only variable from the equator northward but has a diurnal variation to some extent along the shores. At Puget Sound Biological Station the daily variation is only about a half degree, but is sufficient to make a difference in the flora of the upper strata. Furthermore there is a difference in temperature from the surface down, which again accounts for a difference in the distribution of these green plants.

Salinity is another factor in the growth of sea pastures. Along the shores it becomes a great factor because streams flowing into the ocean sometimes make the ocean water near the shore practically fresh. I have seen kelp beds so thick that I could go through them only hand over hand on kelp and have found the water near a river fresh enough to drink. It is astounding how these large kelp beds can develop in such fresh water.

Another factor in the growth of sea pastures is the acidity of ocean water. It requires a very slight difference in acidity to vary the organisms in the water. This holds not only for small but also for large organisms. Dr. E. B. Powers, who has been

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working at the Puget Sound Biological Station on the distribution of fishes and the direction of their movements, finds the difference in acidity to which fishes respond so slight as to be difficult to detect. Dr. Powers believes if we develop the methods of determining acidity sufficiently, it will be possible, by testing the acidity of the water ahead of salmon when they are migrating, to judge with a considerable degree of accuracy where the fish are going. I am not altogether convinced of this myself but he has convinced the British Deep Sea Fisheries sufficiently to cause them to take up that same work in the North Sea this year.

Light is also a great factor. It stands to reason that the carbo-hydrates cannot be produced except in suitable light conditions. Now light does not penetrate to the depth that one might suppose. Some experiments in light penetration have been carried on this summer at Puget Sound Biological Station. I left after the first day's work with the apparatus and can give only the results of that day's work. It was found that, in the bay at Friday Harbor, approximately one-fourth of the light was cut out at the surface of the water, and at a depth of 25 feet the amount of light was reduced to one-twentieth. The ability of light to penetrate the water of Puget Sound is considerably less, at least than I had expected it would be. Now the penetration of light varies greatly with different regions and depends at least to some extent upon the organisms and particles in the water. In the bay at Friday Harbor we have a body of water whose surface layers alone are capable of growing food.

Currents frequently change food conditions in the ocean. Where currents go down the organisms carried with them may meet changed conditions and die. The dead organisms are either eaten by bacteria or settle to the bottom and perhaps become food for fish. I would expect the regions where the remains of animals such as shells are abundant, would be where currents are going down, because there the greatest death rates must occur. I would also expect regions in tropical waters to be mostly free from plant plankton. The currents are the greatest factors in determining distribution conditions.

But it is not only on the surface but along the shores of the ocean that we find abundance of food. Large quantities of seaweeds are produced along the shores of North America

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and, I am told, also along the shores of Japan and Siberia. This is also true of the South American coast from Cape Horn to Peru. I do not know about Australia but suspect there might be large quantities of seaweeds along the shores of that continent. The display of seaweeds in the waters about the Hawaiian islands is difficult to compare with the quantity along the west coast of America where millions of tons are produced annually. We do not know what becomes of these seaweeds. A few of the greens are eaten directly by animals. Some of the browns are eaten by animals as are also a few of the reds, but of the great mass we do not know the end. They decay and disappear, but we do not know what becomes of the decomposed seaweeds. I do not believe that all these millions of tons simply disappear without supplying, to some extent, food for animals. We do not know what seaweeds are attacked by bacteria. There again, however, we are more or less at a loss because bacteria of the ocean seem to be so little understood. I think we need very much the development of ocean bacteriology to inform us what organisms decompose these plants, and what kind of products are formed. Perhaps some of them go out in suspension as colloids. But what becomes of them and of the bacteria is a problem which needs a solution. Ordinarily we must take it for granted that they do not return.

I believe, therefore, that we should form a better connection between the food animals and the plankton on the surface of the ocean, and a better connection between the food animals and the plants that grow along the shores. In fact, I believe one of the most promising problems in fisheries would be to study not only the food of fish, but the food of the things which the fish eat. If we knew the food of the different organisms in the sea, we would be far along in the solution of the fisheries problem. It is probably a zoological problem. I am a botanist. On the other hand botany and zoology are not very far apart. It is certainly as much a problem of the botanist to know what eats plants, as to know where they come from.

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DISPERSAL OF PLANTS BY OCEAN CURRENTS

By William E. Safford

On the windward beaches of islands lying in the paths of oceanic currents there is usually a line of drift just above high water mark in which may be found seeds and fruits of various kinds. Sometimes the material is riddled with teredo borings or covered with barnacles, but often it appears fresh and little worn by erosion. Many of the seeds are probably dead; some of them are alive and ready to sprout, but not all those which actually germinate succeed in gaining a foothold on the strand. Plants which normally grow in muddy estuaries or mangrove swamps cannot establish themselves on a clean sandy beach. Many fruits of Rhizophora, which germinate even before they fall from the tree, are borne away by currents and cast up only to die. Nuts of the nipa palm, though in perfect condition, can establish themselves only within estuaries or the brackish mouths of streams. Coconuts, on the other hand, germinate on sandy beaches and establish themselves also in crevices of coral reefs. There can be no doubt that they maintain themselves in a state of potential germination, after having long drifted over the surface of the ocean, as Beccari has pointed out.

Not only the coconut but many other strand plants have fruits and seeds peculiarly adapted for floating. Some of the so-called sea-beans inclose a large air-space either between their cotyledons, like the snuffbox bean (*Entada scandens*), or between the cotyledons and the shell, like the hard gray stony nickernut (*Guilandina crista*). The seeds of certain Convolvulacrae belonging to the genus Operculina, often cast up by the sea, are heavier than water, but they are inclosed in an inflated membranous bladder which keeps them afloat for many weeks.

On the island of Guam, in addition to the more common strand plants, I have picked up on the beach the compound fleshy fruits of *Morinda citrifolia* called *noni* by the Hawaiians and *nona* in the Malay Archipelago. Each seed of this plant contains a distinct air cell. Another fruit frequently found on the strand is that of *Barringtonia speciosa*, which owes its buoyancy to its spongy husk, and the same is true of an Apocynaceous fruit belonging to the genus Ochrosia. On the island of Guam I also gathered other seeds and fruits of strand plants: Rhizophora, Bruguiera, Lumnitzera, *Heritiera littoralis*,

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Hibiscus tiliaceus, Thespesia populnea, Terminalia catappa, and *Calophyllum inophyllum.*

It is interesting to note that "sea-beans" played an important role in the discovery of the existence of the Gulf Stream. Certain seeds were figured as early as 1693 in an account of objects cast up on the shores of the Orkney Islands. They were recognized by the old botanist Hans Sloane as the seeds of plants which he had seen growing in the West Indies and which were included in his catalogue of the plants of Jamaica. Their occurrence on the shores where they were picked up, so remote from the place of their origin, suggested to Sloane the existence of the current which was afterwards designated the Gulf Stream. Sloane published a paper on the subject in 1696, in which he for the first time offered to the world the true explanation of the means by which these seeds had been transported.

In the Pacific Ocean the warm Kuro Siwo, or Japan Current, corresponding to the Gulf Stream of the Atlantic, flows northward along the coast of Asia then eastward until it strikes the opposite continent and then curving southward, and returning upon its course, often deposits great pine logs on the shores of the Hawaiian Islands which it has carried from the northwest coast of America. Strange to say, very few plants from the northwest coast of America have established themselves on the Hawaiian Islands. Dr. Hillebrand has discussed this matter in the introduction to his Flora of the Hawaiian Islands. The existence of many strand plants of southern Polynesia in the flora of Hawaii has been attributed not to ocean currents but to human agency. Dr. H. B. Guppy, who spent many years in studying the subject of the dispersal of plants, has devoted several chapters to Pacific Island floras, including the Hawaiian strand flora. He has also discussed at length the littoral plants and currents of the Pacific, the germination of floating seeds, the buoyancy of seeds and seed vessels, and the relation between littoral and inland plants. With his great work on dispersal, published as the second volume of "Observations of a Naturalist in the Pacific," as a guide, it is hoped that much may be accomplished by future students of ocean currents.

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PRELIMINARY STATISTICAL STUDIES OF MARINE PHYTOPLANKTON OF THE SAN DIEGO REGION, CALIFORNIA

By W. E. Allen

INTRODUCTION

Recognizing the basic need of a better understanding of the occurrence and distribution of the synthetic organisms of the sea, the phytoplankton, the Scripps Institution for Biological Research has in the past four years devoted a considerable portion of its resources to increased investigation of these organisms. The methods of work have been somewhat modified in the last two years along lines of standardization and consistency, but no report on this period is yet available. This paper and the one by Ellis L. Michael which follows discuss the work on phytoplankton of the Southern California region in 1917 and 1918 and are intended to not only give some idea of the preliminary work already done in Pacific waters, but also to offer suggestions for guidance in future operations, either localized or general. These two papers although complete in themselves are based on the same records of numerical distribution and it is therefore desirable to publish them together. The more elementary paper which includes the records essential to both discussions is placed first because that seems to be the natural order.

Much of the work on phytoplankton done in Atlantic waters and in fresh water lakes and rivers shows two desiderata to be especially prominent. First, it is necessary to identify the species present; second, it is essential to maintain, as nearly as possible, continuous observation. It seems appropriate to discuss briefly these desiderata and certain other general features of marine work in phytoplankton before entering upon the explanation of the work done in 1917 and 1918.

DESIDERATA

The taxonomy of dinoflagellates of the San Diego region has been well covered by Professor C. A. Kofoid of the University of California. But this region is an infinitesimal portion of the area of the North Pacific and a great deal of strictly taxonomic work remains to be done. Not even an effective beginning has been made on the taxonomy of diatoms of the North Pacific. Fortunately for our work with both types of organ-

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isms, it appears that the more abundant, more prominent, and presumably more important forms are cosmopolitan and fairly easy to recognize. Preliminary statistical work gives little indication that *refined taxonomy* is of immediate importance, but it ought to be done in preparation for any future time when specific determinations of great accuracy may be needed for interpretation of some series of records.

One of the most, if not the most, urgent need in connection with statistical work with the microplankton is for the establishment of definite stations from which collections may be taken with great frequency and continuity, daily if possible. There ought to be at least one permanent station at which a permanent series may be run to serve as a standard for the work in any given area. With such a standard much effective work can be done by running daily or hourly catches through any one desired or immediately possible period of the year. Of course, it is highly desirable to have such series carried for various depths as well as for the surface but it is quite evident that the field of surface catches has scarcely been touched in most localities and that it still offers ample opportunities for work for many years to come. For practical purposes anything in the uppermost five meters of water may be regarded as belonging to the surface series. One distinct advantage of a standard series of surface catches is that it may serve as the basis of comparison not only of series from other surface areas but from various depths as well. A still greater advantage is in the greater simplicity of procedure and equipment required for surface work. This is of high importance because it vastly increases the probability that the series can be carried continuously. To those who realize the time, work, expense and risk in handling such series it is evident that a break in continuity after one is once established may be a very serious matter, hence anything that will tend to insure its satisfactory maintenance is extremely desirable.

If a good quantitative series is once opened it would be very desirable to have any particular phase of the work handled as nearly as possible by the same individual. Slight changes in individual methods sometimes produce great differences in the final quantitative results.

POSSIBLE COMMERCIAL APPLICATION

Aside from the academic interest it has in extending our knowledge of the laws of life and in broadening our conception

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of the phenomena of organic existence, I think the study of marine plankton may finally be made to have a decided practical value. The sections following illustrate possibilities.

Naturally, the food relation is the first to attract attention. If a series of records can be secured which will enable us to say that with a certain number of clear days in February and March the seasonal catch of marketable fish may be large because the photosynthetic organisms are able to build up enough food material to supply abundantly the next link in the chain which in turn may supply the next, and so on, up to the fish, it would be worth while even though the information is somewhat indefinite and faulty. Or, if we are able to say that a smaller number of clear days means a poor supply for the markets, or that existent pasturage can support only a limited population, or that certain fishes might be introduced to use it to better advantage, those concerned may be on their guard and not be taken entirely unawares. Some such predictions have been made in connection with fisheries in the North Sea. Judging from present knowledge it is reasonable to hope that if we do our work properly some succeeding generation may be able to make reports to fishermen quite comparable in value to those now made by the weather bureau to farmers. It may be found that some organisms which do not seem to have much value in the food chain, do have a direct value as indices to productivity.

There is another relation which may be as important as the food chain. That is the poison (or at least we may say the exclusion) chain. I mention this because of the considerable evidence to show that certain dinoflagellates may be fatally injurious to fishes and other organisms. If records were available to show the conditions under which such organisms become so numerous as to be of economic importance, advance report of the coming of such conditions might forewarn fishermen and so, to a considerable extent, forearm.

SOURCES OF ERROR IN STUDY

Sources of error have to be considered in connection with any piece of work which pretends to any degree of accuracy. I have taken a good deal of interest in these sources of error and since no considerable number of them is ever mentioned collectively, I have attempted to make a bare list of those most important in such plankton methods as are in general use. Some are important always; some are usually negligible; some counteract

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or cancel others at times. These conditions are themselves variable and so subject to error of usage and interpretation. For convenience we may call the conditions in which sources of error reside, variants. They may be enumerated as follows:

Variants in sampling.
- Selecting the station in the area.
- Locating the station in the area.
- Drift while hauling { Distance, Speed, Direction }
- Descending catch in net.
  - Pitching of boat (especially if vertical haul).
  - Cross currents.
- Ascending catch in vertical hauls.
  - Pitching of boat.
  - Clogging of net.
  - Leakage of net.
    - Pressure.
    - Mesh.
  - Speed of haul.
  - Cross currents.
- Taking from net.
  - Spillage.
- Recording.
- Preservation.
  - Distortion.
  - Fragmentation.

Examination.
- Dilution or concentration.
- Transference, spillage and adhesion.
- Measuring.
- Mixing.
- Sampling for count.
- Counting.
  - Fractional sampling of the slide.
  - Miscounts { Small size. Distortion. Covered by debris, etc. Uneven distribution in counting cell. Personal error, fatigue, etc. Bad position for identification. Misnaming. }

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Recording.
Computing.
Recording.
Interpreting.
Differences in persons.

This looks like a formidable list, and it is. That is one reason why it seems necessary to simplify and to standardize all methods of collecting and handling as much as possible. One unfortunate effect of the contemplation of such a long list of variants is the feeling that any one error will be so much over shadowed by other errors as to be negligible, but it is evident that a minor variant may become very important if carelessly regarded, and that reasonable uniformity of degree of error is more important in a series than is extent of error. A large error clearly recognized may be less injurious than a small one left without consideration.

LENGTH OF PROGRAM

My experience with these preliminary studies leads me to believe that the most valuable plankton work will be that which is done laboriously over long periods of years. By such work errors or abnormalities of one year or season may be checked by many others so as to give a fair general view of conditions to be expected in a given area. It seems to me that the laws of distribution of life in the sea must be fundamentally the same as those governing life on land and in air. There are areas in the sea with little or no life, and all gradations between this condition and that of great abundance of life. Evidently, many organisms shift, voluntarily or involuntarily, from one area to another. Certainly there are vacillations in productivity corresponding with vacillations in the vast numbers of factors of environment.

These factors of the environment are so numerous that their possible permutations and combinations seem past finding out. The list of chemical factors alone, must be for the sea almost as large as the list of soluble chemical elements and compounds. The list of physical factors, while possibly shorter, is still very long and of primary importance, for example, temperature has a profound influence on the effect of many other factors. Furthermore, the number of biological factors is legion. Surely, with all this complexity, we cannot hope for clear insight until there are enough records to show certain combinations with sufficient frequency to fix our attention.

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MATERIALS AND METHODS

I consider microplankton particularly useful for the study of these combinations because of the vast numbers of its organisms, their limited motility and their high adaptability through reproduction. Their short life cycles are also a point in favor since the effects of given conditions can be more quickly seen. Large numbers of individuals and large numbers of kinds in a given plankton population are both important in helping to reduce some of the errors in handling and study. Different species, for example, check each other to some extent and so aid in giving proof or in calling attention to error.

These studies were made in the summers of 1917 and 1918, on miscellaneous and somewhat heterogeneous groups of catches made from time to time and kept in storage. Most of the catches were made in the years 1917 and 1918 and some were studied within ten days after being taken.

As described in the detailed discussion the methods of making the catches varied. Methods of counting differed somewhat but most of the counts were made by the Sedgwick-Rafter method. The catch in its preservative formalin was brought to a standard quantity, one cubic centimeter of which was taken after thorough mixing and placed in a Sedgwick-Rafter slide. The count was then made under the low power of the compound microscope using a Whipple eyepiece micrometer with draw tube so adjusted as to cause the scale to cover one square millimeter in the field of the sixteen millimeter objective. If the catch was large a count was made of fifty fields (covering fifty cubic millimeters of fluid), distributed in groups of five about the margins and middle of the slide. Finally a half slide was examined for less abundant forms which were duly counted. If the catch was light half slide counts only were made. The counts were afterwards used to compute the total numbers in the catch and the results were tabulated according to taxonomic groups.

Diatoms and dinoflagellates only were counted as the other micro-organisms in the plankton were too few to be of much value for statistical studies. In fact it appears that diatoms are much superior to dinoflagellates for this purpose. Most of the numerically important forms in both groups are usually easy to identify. Some of the less abundant forms are easily confused under conditions of counting and others cannot be identified

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with certainty. In some cases it has been impossible, on account of small size, to distinguish some of those which have numerical importance. Some diatoms have not been specifically identified because too fragmentary or because spore stages were not found. There is no evidence that this deficiency has been sufficiently important to appreciably diminish the value of this statistical work.

MINOR STUDIES

STOMACH CONTENTS OF SARDINES AND ANCHOVIES

A very limited qualitative study was made of stomach contents of sardines (*Sardinella coeruleus* Starks and Morris) and anchovies (*Engraulis mordax* Girard) which serve as food for the albacore (*Thunnus alalunga* Gmelin). Five anchovies taken from the stomachs of three albacore were examined on August 13, 1917. The stomach contents of three of these were wholly unrecognizable. Of the other two, the little which was recognizable consisted of the shells of diatoms and dinoflagellates of various kinds, most of which could not be specifically identified. Three sardines taken at the Institution pier were examined. In two specimens remains of the dinoflagellates *Dinophysis homunculus* Stein and *Prorocentrum micans* Ehrbg. were found but about ninety-nine per cent of the stomach contents consisted of copepods. In the other sardine the following diatoms and dinoflagellates were found in quantity: *Coscinodiscus* sp., *Chaetoceras criophilum* Castr. and a number of smaller diatoms; *Peridinium divergens* Ehrbg., *P. grandii* Ostf., *P. oceanicum* Vauh., and many fragments of shells of Ceratium. This study was not carried further because it was only confirmatory of the well established idea of the important part which diatoms and dinoflagellates play in furnishing food for fishes or their prey.

SOME CASES OF "RED WATER"

Some isolated qualitative studies of "red water" and similar phenomena were made. These have value in a statistical series because they prove the occurrence of various species of microplankton in enormous swarms and consequently refute the old notion of uniform distribution of small organisms in sea water. Only two of these will be specifically mentioned here. On June 4, 1917, "red water" was encountered at a point about twelve miles west of San Pedro, where three hauls taken at depths of thirty meters, sub-surface and of surface "scum"

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showed the surface "scum" to be composed of *Prorocentrum micans* Ehrbg., the sub-surface haul to be composed mainly of this dinoflagellate, and the thirty meter haul to be composed mainly of diatoms and other dinoflagellates. This case of "red water" indicates the probability that plankton swarms are not only definitely limited in surface area occupied but also as to depth.

Another case of "red water" occurred on September 11, 1917, close inshore near Santa Barbara where it was causing a good deal of injury to fish and shore fauna and exciting much inquiry. Captain W. C. Crandall of the Scripps Institution made a special trip to get samples of this swarm. He made a total of twelve surface hauls nearly all of which consisted mainly of *Gonyaulax polyedra* Stein, some almost entirely so.

These two typical cases show not only that plankton swarms occur both inshore and off shore, but that they are to a very large extent exclusive against other organisms in their particular area many of which in fact, are killed.

SOME CASES OF LUMINESCENCE

In this connection mention may be made of some qualitative catches made by Mr. James Ross along the coast of Lower California in the Spring of 1919. Early in March a rather rich diatom plankton was found slightly to the north of Magdalena Bay. The Bay itself yielded little in the two catches made. Near Cape Magdalena there was an area of marked luminescence, but little microplankton. The presence of a few Ctenophores in the catch suggests their agency in this phenomenon. In Santa Maria Bay and at Santa Margarita Island catches showed large quantities of *Lauderia borealis* Gran. Brilliant luminescence was reported there which was also probably due to Ctenophores. In the Gulf of California near Espiritu Santo Island where remarkable luminescence was reported, it again seems probable that Ctenophores were responsible. Near San Martin Island an area of "brown water" was reported which was about fifty miles in extent. Catches from it consisted mainly of *Chaetoceras debile* Cl. and *Nitzschia seriata* Cl. Transtitions from luminescent to non-luminescent areas were very sharp. Transition from "brown water" to non-brown was more gradual.

SOME CLOSING NET CATCHES AT VARIOUS DEPTHS

On June 14, 1917, Mr. James Ross and Mr. P. S. Barnhart made a short series of closing net hauls at the kelp beds one

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and one-half miles west of La Jolla Point. These were taken from 5, 10, 15, 20, 25, and 30 meter depths and one was taken from the 44 meter level to the 30 meter level. They were taken successively as rapidly as possible beginning at 10 a. m. This single series showed quite clearly a scant microplankton population in the upper fifteen meters and heavy catches from the 20 meter level to the 44 meter level. Of course, no real conclusions can be reached from a single short series of this sort, but there are some interesting questions suggested by it. Perhaps the most important of these is as to whether large quantities of microplankton frequently occur near the 50 meter level or whether abundance below thirty meters may have been due in this case to mixing by currents induced by proximity to the shore line. There is also the important question as to what factors determine the level at which most microplankton may be found.

SEASONAL SERIES

We may now consider the "seasonal series" so called because it consists of a series of catches made at nearly weekly intervals at two certain stations, two and five miles off shore respectively from the Scripps Institution. This series ran from December 12, 1917, to July 11, 1918, covering approximately the most productive plankton season (judged from our other records). It was not possible to make many of these catches at Station 2 (five miles off shore) partly because of rough weather and partly because of lack of time necessary to do the work with the small boat available. For similar reasons some important breaks occurred in the series from Station 1 (two miles off shore). In spite of these deficiencies the series has a decided interest for comparison with other series and it also gives some valuable indications as to seasonal distribution and ecological successions. The most important points are the showing of a prominent diatom pulse in January characterized especially by *Chaetoceras curvisetum* Cl. and *Ch. convolutum* Castr., an enormous diatom maximum late in May characterized by *Chaetoceras criophilum* Castr. and *Ch. convolutum* Castr., a dinoflagellate pulse in December due to *Ceratium fusus* Ehr. and a dinoflagellate maximum in mid May due to *Peridinium crassipes* Kof., *P. divergens* Ehr. and *Ceratium furca* Ehr.

Next, we may consider the various series of catches made on special collecting cruises of several days duration at different periods in 1917 and 1918. These will be discussed in chrono-

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logical order. Methods of making the catches differed somewhat with different cruises but all counts were made by the Sedgwick-Rafter method. Inasmuch as little comparison was made of catches of one series with those of another, the differences in collecting methods are not important for the purpose of the present paper.

PRINCIPAL STUDIES. LATERAL SERIES

FIRST SERIES. JULY A (1917)

The first series (July A) was made on a run from a point about fifty miles west of San Nicolas Island in to San Pedro on July 14 to 16 inclusive. In this series hauls were made with the fine meshed net (No. 25) from a depth of 200 meters to the surface at eighteen stations selected at more or less regular intervals on the run in. Of the eighteen stations hauled, only six showed large amounts of microplankton. Of the six two were farthest seaward, two near inshore and the other two at about equal distances between. At all of the other stations the catches were light or even scanty. Station 11 near San Nicolas Island gave a rather large amount and the catch near Point Fermin was especially large.

Five different diatoms were dominant numerically at one or more stations. *Chaetoceras affine* (?) Lauder was most abundant at the two stations farthest seaward and at Station 17 just north of Catalina Island. *Ch. criophilum* Castr. was dominant at all stations from 2 to 13 inclusive, except Station 11. It was much in excess of other diatoms at Stations 7 and 8. *Nitzschia seriata* Cl. was dominant at Station 14 and *N. longissima* Breb. at Stations 16 and 18, excessively so at the latter. It now becomes necessary to refer to a series of surface catches made from a similar run in June which was not studied in detail. The point of interest is that the June series showed a very marked dominance of Chaetoceras *criophilum* Castr. or of *Nitzschia seriata* Cl. at almost all stations in June, while in the present series they are barely able to keep a lead. Smaller Chaetoceras forms have replaced *Ch. criophilum* to a large extent in most cases. It is also true that *Nitzschia longissima* Breb. is smaller than *N. seriata* Cl.

The evidence from the July A series points superficially to the view that microplankton is more abundant inshore and near islands. Volumetric studies and statistical analysis of this material made by E. L. Michael show, however, that these differences

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were due to changes from old to new nets on account of loss or tearing. Since we have no accurate indication of the differences in nets no conclusion is possible from this evidence though there is some indication of maximum microplankton production seaward.

SECOND SERIES. JULY B (1917)

Another run was made in July which yielded the July B (Table II) series. This run (July 29 and 30) was from a point about fifteen miles west of Tanner's Bank to a point about five miles east of San Clemente Island. The twelve catches of this series were made by vertical hauls from a depth of 200 meters. This series consisted of light, or even scanty, catches throughout, and the diatoms were largely fragmented or otherwise in poor condition. They were mostly very small, many were atypical, and species distinction was much more difficult than formerly in the dominant forms.

Dinoflagellates in this series, as was also the case in the July A series, seemed in fair condition though few in numbers.

Since this series did not extend inshore on account of breaking of apparatus, there is no means of comparison of relative abundance inshore and offshore at the time it was taken. It may be noted, however, that this series agrees with July A in showing *Nitzschia longissima* to be distinctly characteristic of seaward plankton at this season.

The main points suggested by this series are that there is not uniformity of distribution of plankton forms over an area and that there is a still later stage of diatom decline than was shown by the July A series. It is notable also that *Dactyliosolen tenuis* Cl. was dominant at Station 9 in the midst of an area mainly characterized by *Chaetoceras contortum* Schütt, a fact which shows the possibility of a local break in a widespread dominance.

THIRD SERIES. AUGUST (1917)

One run was made in August and the twenty-eight catches then made constitute the August series. These catches were all made by vertical hauls from depths of 200 meters. This was a long run on zigzag lines from San Diego to Santa Cruz Island, and it extended from August 11 to August 20 inclusive. On account of its zigzag character, this series cannot well be considered as a whole, hence it may best be broken up into six subseries conveniently lettered A, B, C, D, E, and F. It may as

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well be stated here, however, that this series, as a whole, seems to show about 50% larger numbers of dinoflagellates than were shown in either July series. It appears that there were less than half as many diatoms as in the July B series and only about one-fifth as many as in the July A series. So far as the 1917 summer records are concerned, then, the general numerical increase of dinoflagellates in midsummer is not marked in this region as it is reported to be in others. The diatom decrease is thus prominent, however. Inasmuch as we know of vast localized increases of dinoflagellates at this time it may be thought that, on the one hand, dinoflagellates are less stable and more localized in distribution than the diatoms, or, on the other hand, that they have an apparent prominence due to the absence of large numbers of diatoms.

This latter view is somewhat supported by the fact that "red water" due to vast numbers of dinoflagellates was reported at various places at about this time. It is also true, however, that more dinoflagellates might escape through the meshes of the net when diatoms are few (because of less clogging) and thus the real increase in numbers would not be shown in the catches. In addition, it is necessary to remember that we do not know as yet the history of the cycles run by these organisms in this region.

Sub-series A, consisting of six catches, covers the line between Point Loma and San Clemente Island, which was omitted in the July B series. It gives some indication of an increase of plankton content inshore, but as the nearest station to the shore was fifteen miles out, the ground of inference is not very certain. The largest numbers of both diatoms and dinoflagellates were caught midway between San Clemente Island and the mainland.

As to the numbers in this sub-series, *Chaetoceras affine* Laud. was dominant at the two stations nearer San Clemente Island, while a small, unidentified species of *Navicula* was most numerous toward the mainland. Since this small *Navicula* seemed to be in fairly good condition it may have been a forerunner of the cycles leading to the autumnal increase in the diatom population.

About the only inference to be derived from this sub-series is that different stations present differences in kinds and relative numbers of organisms.

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Sub-series B, consisting of four catches between San Clemente Island and Oceanside, shows nothing of very great prominence, except that the smallest numbers of both diatoms and dinoflagellates were found at Station 9 midway between San Clemente Island and Oceanside. Inasmuch as this is almost directly opposite to the condition in sub-series A, it might at first be thought that the showing was due to leakage of the net or some other accident in hauling of the net at Station 9. Station 8, however, is also low in numbers, and it may be that there actually was such remarkable scarcity of all diatoms and dinoflagellates at Station 9 as the records show.

Chaetoceras affine was dominant at all four of the stations in this sub-series, except in the small catch at Station 9, where *Peridinium crassipes* was most numerous.

Sub-series C includes five stations on the line from Oceanside to Santa Catalina Island. It, also, is mainly impressive through the fact that a very low minimum for both diatoms and dinoflagellates occurs at Station 14, midway between the island and the mainland. In this case, however, the maximum for diatoms occurs about six miles nearer Santa Catalina at Station 16, while the maximum for dinoflagellates occurs at Station 16, about eight miles from Catalina. The small *Navicula* sp. was dominant at three stations, *Chaetoceras affine* at one and *Peridinium cerasus* at one.

Sub-series D includes three stations between Santa Catalina and San Pedro. It agrees with the July series in showing a marked increase of diatoms nearer San Pedro. This is not yet accounted for in this series. *Chaetoceras affine* and a small *Navicula* sp. are the numerical dominants at stations 19, 17, and 18.

Sub-series E includes six stations from Pt. Fermin to the vicinity of Santa Barbara Island. As far as it goes this sub-series covers a good deal of the same ground covered by the July 1917 series. For this reason it has more interest than the other sub-series in this group.

Both diatoms and dinoflagellates appeared in largest numbers at Station 26 about six miles southeast of Santa Barbara Island. The numbers at Station 20 near Pt. Fermin were decidedly smaller. This distribution is markedly different from that in the July 1917 series when the station near Pt. Fermin showed largest numbers of all. As noted in discussing that series this

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showing of the July series was due to the net. Hence the showing of the August series is probably correct.

Nitzschia seriata was numerically dominant at the three stations farthest seaward, occurring in relatively enormous numbers at the two stations nearest Santa Barbara Island. This is approximately the general region in which it was especially prominent in the June series and the July 1917 series. The small Navicula was most numerous at Station 21, and *Chaetoceras affine* at Stations 22 and 20.

This sub-series shows plainly that there are marked differences in plankton content in different localities. While it does not support the questionable indication of the July 1917 series that heavier plankton occurs close inshore, it does show some resemblance to that condition by its heavier plankton being found near Santa Barbara Island. The dominance of *Nitzschia seriata* in the region near this island at three different times suggests the possibility of an organism being characteristic of a given area over a considerable period of time.

Sub-series F includes four stations not covered in such a way as to be directly comparable with the other sub-series. Station 40 was just north of Santa Cruz Island. *Nitzschia seriata* was distinctly dominant here, giving the impression that something in nearness to islands favors it. The catch as a whole closely resembled others in the main series except that dinoflagellates were made prominent by large numbers of *Gonyaulax polyedra*.

Stations 50, 51 and 52 were about fifteen or twenty miles from Oceanside. Nothing of prominence appears in their records to indicate much difference from conditions in that region a week before, except that Station 51 is almost identical with Station 10 and it shows a dominance of the small Navicula, instead of *Chaetoceras affine* as at the other time.

Considering this August series again as a whole, it is interesting to note that *Chaetoceras affine* is dominant at ten stations out of the twenty-eight, the small Navicula at twelve stations, *Nitzschia seriata* at four stations, *Chaetoceras decipiens* at one station and *Peridinium cerasus* at one station.

COLLECTIVE DISCUSSION OF 1918 SERIES IN COMPARISON WITH 1917 SERIES

The work in 1918 was along lines somewhat similar to those of 1917, hence it may be most conveniently discussed by making comparisons. Only two additional points seem to be

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clearly indicated. First, it seems almost certain that the production of diatoms reaches a maximum somewhere from April to early June, a conclusion which agrees with the results of various European observations. Second, owing partly to the use of the shorter, fifty meter vertical haul, a complete series of catches with the No. 25 net was made on the long August trip, even including catches in the Santa Barbara Channel and beyond Point Conception.

Monthly cruises (except April) were made from January to August in 1918. The January trip shows nothing of particular note unless it be that *Chaetoceras criophilum* Castr. is the most prominent microplankton in nearly the whole lot of rather light catches. February catches were slightly heavier with a predominance of *Chaetoceras curvisetum* Cl. In March *Chaetoceras curvisetum* retained its dominance in much heavier catches. *Nitzschia pungens* Grun. was most abundant at the two stations east of San Nicolas Island, however. In May *N. pungens* was much the most prominent microplankton at all stations beyond Santa Barbara Island. Considering the small size of this diatom and the probable heavy losses through the net, this is a remarkable showing in a group of rather heavy catches. *N. pungens* retained its prominence in June, *N. seriata* being next most abundant. Considering the opinion of some experts that *N. pungens* and *N. seriata* are merely different forms of the same species, this fact has considerable interest. Catches in June (Table III) were distinctly lighter.

Some details of the August records require more attention than those for other months. For one thing, there is the same relative scarcity of microplankton at the two stations (No. 6 and No. 7) midway between San Clemente and Oceanside, as has already been noted for the August trip of 1917. It is interesting to see that this 1918 cruise also shows a similar scarcity at Station 10 midway between San Juan and Santa Catalina Island. As yet there is no means of knowing whether this is the typical condition in those localities, but there is some probability that it is and the question of the possible explanation is interesting. The distance from land is not such as to make it probable that dearth of organic matter is the cause. Other factors must be responsible for the peculiar condition. The most likely explanation seems to be in some peculiarity of the currents.

Another interesting feature of this August trip is its greater extent beyond San Nicolas. As a matter of convenience in tabu-

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lating the records, the stations near and beyond San Nicolas have been arbitrarily grouped together into an "off shore group" by way of contrast to the "south inshore group" between San Diego and Santa Barabara Island and the "north inshore group" north of Santa Cruz Island. This "off shore group" showed large numbers of diatoms to quite a distance beyond San Nicolas, but there was a very marked reduction in numbers at the seven stations fårthest out. This reduction was not so marked for the dinoflagellates which kept up their numbers fairly well at the outer stations. The larger number of both diatoms and dinoflagellates in the vicinity of Point Conception is quite noticeable and leads to the question as to whether this indicates a later maximum of microplankton production in that region than we have found farther south. Another feature of this August series is the prominence of *Rhizosolenia calcar avis* Schultze. At about the same time in 1917 *Nitzschia seriata* Cl. was much the most prominent in similar locations. This condition may be due to a difference in seasonal dominants.

From some extra hauls in the August series a comparative study was made of the results of vertical hauling at depths of 200 meters and at the surface in addition to the regular vertical hauls of fifty meters. Too few hauls were taken to be conclusive. In this case the catches were not greatly different except that the surface hauls appeared rather light, and this may have been due to difference in hauling. Vertical hauls of 200 meters and fifty meters were much alike, a fact which indicates that practically all of the microplankton is usually to be found at less depths than 50 meters.

SUMMARY OF RESULTS OF STUDIES OF LATERAL SERIES OF 1917 AND 1918

The summary of the results of these studies requires little space.

1. It is fairly evident that diatoms usually exceed dinoflagellates in numbers and also in bulk. August and September seems to be the only period of the year in which there is extensive exception to this rule. There is some evidence that maxima of dinoflagellates come with minima of diatoms and vice versa.

2. There is strong indication that annual maxima for both diatoms and dinoflagellates occur in the period from April to early June.

3. There is indication that the minimum of diatom production for the year comes in August or September.

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4. There is some evidence that the annual minimum of dinoflagellate production comes sometimes in the winter. It would also appear that dinoflagellates are much more unstable in occurrence than diatoms. These differences may prove of distinct value in interpretation of relative distribution of microplankton in the sea.

5. It is very evident that plankton content differs markedly in different areas at a given time and in a given area at different times, even at short intervals.

6. It is very evident that plankton collections taken at long and irregular intervals of time are of little value for statistical study of the biology of the sea.

7. It is necessary to improve and to standardize the methods of collecting. Some way should be found to locate the organisms more accurately, to make the records more nearly continuous, and to place all phases of the work in the hands of skilled, interested and persevering workers. Otherwise the work will remain at the dead level of repeated preliminary activities for which no advance is provided.

8. The problem of marine plankton distribution is almost identical with the problem of marine life, one of the most difficult problems which the human mind can set for itself. It cannot be completely solved in a day, or a year, or a century. It requires a long series of observations at many definite stations in definite areas, made through frequent collections during decades or centuries of time. Continuity of effort both in time and space is essential to real progress toward solution of plankton problems.

9. The marine plankton problem is, for practical purposes, a problem of ecological cycles, associations and successions. It is distinctly general rather than specific in nature.

10. There is little hope of commercial utilization of studies of marine microplankton until methods have been made more exact and more nearly standardized, and until trustworthy records have accumulated to such an extent as to compare favorably with the records which are used for tidal and meteorological predictions. Instead of being content with distinguishing biological sciences from "exact sciences", it would be worth while to see how exact they can be made.

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NOTE ON THE TABLES

On account of the preliminary character of these studies it has not been considered necessary to print the complete records, hence the tables for July 1917 and June 1918 are the only ones included with this paper.

All catches were made by vertical hauls with the number 25 tow net. Hauls for 1917 were from depths of 200 meters to the surface. Those for 1918 were from depths of fifty meters to the surface. Numbers given in tables are estimated totals in each catch of any species or designated group. Where two numbers are given the smaller gives the number of colonies.

The map accompanying the paper by E. L. Michael published in the proceedings of this Conference covers most of the territory referred to in this paper.

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EFFECT OF UPWELLING WATER UPON THE ORGANIC FERTILITY OF THE SEA IN THE REGION OF SOUTHERN CALIFORNIA

By Ellis L. Michael, Scripps Institution for Biological Research

INTRODUCTION

With remarkably few exceptions, marine animals depend finally for food upon microscopic one-celled plants living at or near the surface of the sea, which, taken collectively, are called phytoplankton. The albacore, for example, feeds upon sardines. sardines upon copepods, and copepods upon constituents of the phytoplankton. So with the barracouda and yellow-tail. Other fishes, like halibut and cod, which inhabit the sea floor or deep water, feed upon molluscs, worms, and crabs of the bottom, or upon carcasses of plankton animals intermixed with bottom mud or caught in their descent from the upper layers of water. But the food of the food of these deep water fishes consists of diatoms or other constituents of the phytoplankton, or of plankton animals which feed upon these plants. So with the vast majority of other marine animals. The number of links in the food chain connecting any particular one with the phytoplankton may be few, as in the case of a copepod, or many, as in the case of a seal, but, in each instance, they lead to and terminate in the minute plants inhabiting the surface waters.

The part played by the large algae and seaweeds upon the metabolic cycle is indirect, though it is probably important, especially in inshore areas. "The sea," say McClendon, Gault, and Mulholland (1917, p. 37), "may be compared to the body of one of the higher vertebrates. The mammal regulates the P_H of the blood through the action of the respiratory center. The sea regulates the P_H of its surface waters most probably through the action of seaweed." Bearing on this point, Mayor (1919, p. 152) says: "Photosynthesis by marine plants in sunlight is a very important factor in controlling the hydrogen-ion concentration of the water of shallow lagoons or tide pools where the bottom is covered with seaweed; for the plants reduce the CO_2, thus setting free oxygen and causing the water to become highly alkaline." Mayor then cites, as an example, the fact that "While the [P_H of the] sea around the Tortugas is about 8.22, that of the lagoon rose at times to 8.35 by day and sank to 8.18 at night . . . ." Although no appreciable diurnal variation

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has yet been detected in the open sea, even in the vicinity of the kelp beds off La Jolla, evidence is later adduced which supports, in the main, the above statements, providing seaweed be considered as including the phytoplankton as well.

However extensive the regulatory effect of seaweeds—as such—may be, the fact remains that phytoplankton is the last link in the food chain, and, hence that its quantity is a measure of the fertility and productivity of the sea. If, in any year or period of years, this quantity falls below normal, it should, in due time, be followed by a corresponding shortage in animal life, ultimately manifesting itself in diminished fishery returns. Likewise, an unusually large quantity of phytoplankton would permit the existence of a correspondingly large number of animals which, again, should manifest itself in the fishery returns. Such variations in quantity of phytoplankton occur, quite aside from the seasonal cycle of production which leads to a maximum in spring. Knowledge of the causes of this variation, therefore, is of interest not only from a scientific point of view but, bears importantly upon the economic problem as well.

Among important causes of phytoplankton variability off the California coast is probably that of upwelling water. The theory of upwelling is demonstrated by McEwen (1916, 1919), and may be characterized briefly as follows: "A body is in equilibrium on the earth's surface only when at rest. When set in motion by wind or similar force, the effect of the earth's rotation is to deflect its direction of motion to the right of the line of force in the northern hemisphere, and to the left in the southern hemisphere. The northerly winds prevailing off the coast of California thus drive the inshore water seaward in a direction somewhat to the west of south, forming what is known as the California current. The surface waters so removed from the coast are replaced by upwelling of cold bottom water, the immediate hydrographic effect of which is to reduce the surface temperature and salinity."

Since velocity of chemical reaction increases with the temperature, the reduction in temperature probably tends toward a decreased production of phytoplankton. Reduction in salinity, on the other hand, favors an increased production because water of low salinity carries a greater amount of silica in suspension than does water of high salinity, and silica is needed by dia-

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toms—the main constituents of the phytoplankton of the California region—in the secretion of their frustules. Moreover, upwelling water presumably carries to the surface the decomposition products of the carcasses of bottom dwelling animals and of those of pelagic organisms that have accumulated upon the bottom. Chief among these decomposition products are ammonia and similar nitrogenous substances which, in the form of nitrates, are required by plants for protein synthesis; and carbon dioxide needed in the manufacture of carbohydrates.

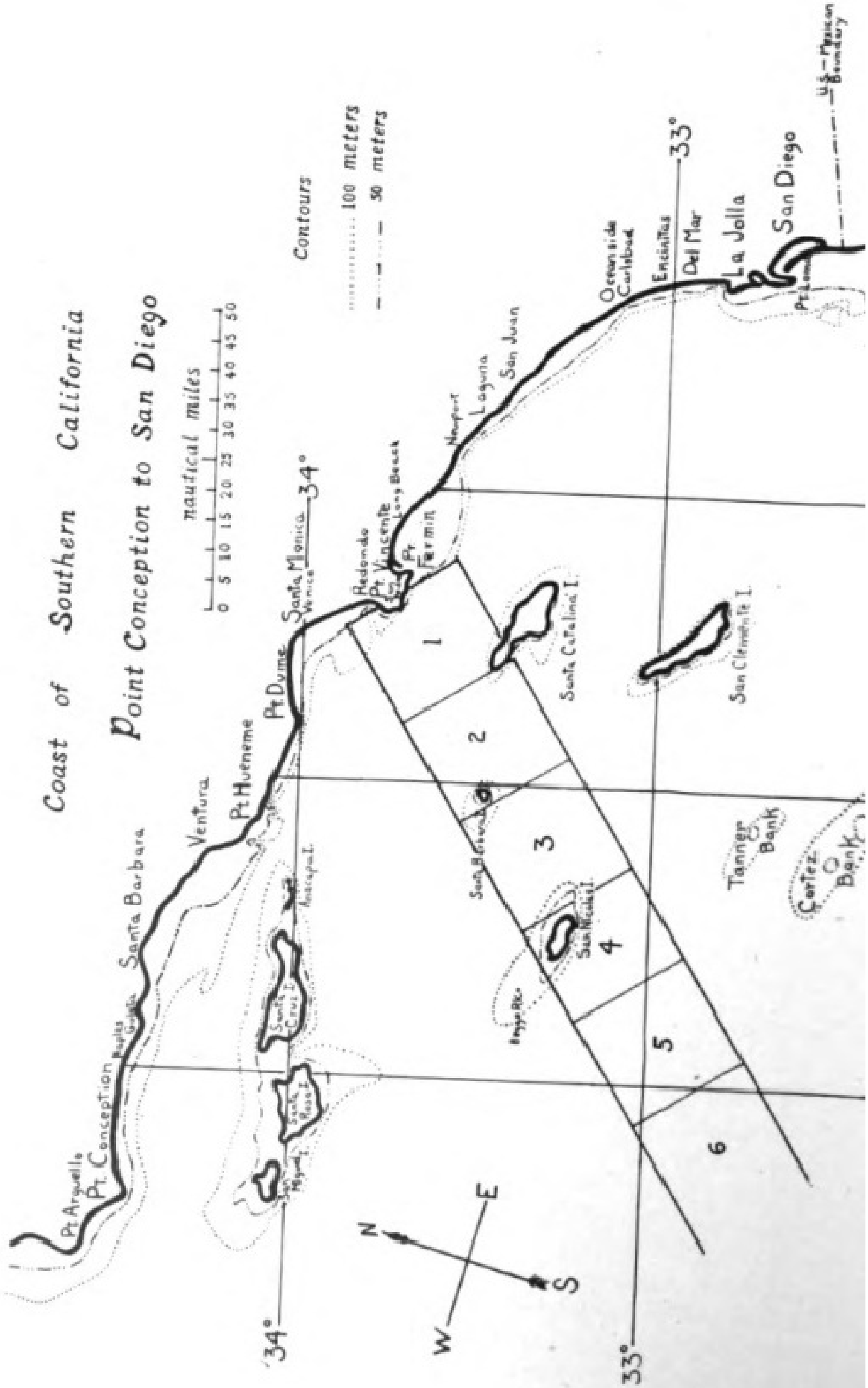
Theory, then, unquestionably points toward an increased production of phytoplankton as a consequence of upwelling water. A statistical study of "field" observations, however, is the only means either of testing the correctness of theory, or, if correct, of ascertaining its significance in the economy of the sea.

It is the purpose of this paper to verify certain essentials of this theory. This is accomplished by bringing into relation to each other fluctuations in amount of upwelling water, measured by its effect on the temperature of the sea, and variations in volume of phytoplankton. Attention is called to the fact that the relation between temperature and phytoplankton affords a simpler and more reliable index to the effect of upwelling than would be the case were either the salinity, carbon dioxide, or nitrogen content used. For, theoretically, the real effect of a decrease in temperature is to decrease the phytoplankton production while the apparent effect, due to upwelling, is to increase it. On the basis of available data, however, it is impossible to carry the investigation to its logical conclusion, and to determine with certainty the law describing this relation, although this law is clearly suggested. Certainty seems to demand large numbers of quantitatively comparable collections made simultaneously at certain critical points along the coast, and at sea, especially during the period of maximum phytoplankton production. It seems also to require material reduction in the magnitude of "field" errors, and direct measurement of the carbon-dioxide, and, perhaps, the nitrogen content and other chemical constituents of the water. The present investigation is but a first step in this direction.

CRUDE DATA

The data upon which this investigation is based consists of one hundred seventy-four collections made from two hundred meters to the surface within a strip of water extending approxi-

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mately one hundred twenty-five nautical miles seaward from Point Fermin (see fig. 1). The series was begun in July 1917 and terminated in June 1918. Each collection was made with a conical net of No. 25 Dufour bolting silk having an orifice six inches in diameter and a slant length of forty inches. Into the peak of the net a four ounce pomade bottle was tied, the quantity of organisms caught in each two hundred meter haul being thus automatically condensed to four ounces. Each collection was further condensed to about three and one-half ounces, and sufficient formalin added to make a five per cent solution. The collections, so preserved, were filed at the Scripps Institution and, in due time, emptied into graduates, allowed to settle for twenty-four hours, and the volume of the sediment measured to the nearest cubic centimeter. Practically all of this sediment is phytoplankton; occasionally a few animals like Salpa were obtained, but were removed before settling. The measurements and relevant data are given in Table I. Suffice it merely to add that a list of the most important species obtained during certain months is given by Mr. Allen in a paper which appears in these proceedings.

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TABLE I. DATA CONCERNING VOLUME OF PHYTOPLANKTON COLLECTED BETWEEN JULY 1917 AND JUNE 1918, FROM A STRIP OF WATER EXTENDING ABOUT 125 MILES SEAWARD FROM POINT FERMIN

Haul	Date		Latitude		Longitude		Distance from Pt. Fermin in nautical miles	Temperature Observed	Temperature R[1]	Phytoplankton Volume	Phytoplankton Log V
	1917										
F12	July	14	32°	57.5'N	120°	1.0'W	92	16.0°C	6.1°C	30cc	1.477
14	"	14	32	55.0	120	5.5	98	16.4	5.8	26	1.415
21	"	14	32	53.0	120	10.0	101	16.8	5.4	21	1.322
23	"	15	32	51.5	120	14.0	108	16.8	5.4	24	1.380
32	"	15	32	59.0	119	57.0	88	16.2	6.0	50	1.699
34	"	15	33	1.0	119	57.0	88	16.6	5.5	56	1.748
42	"	15	33	2.5	119	48.0	85	16.6	5.5	84	1.924
43	"	15	33	4.0	119	43.0	79	17.4	4.7	56	1.748
52	"	15	33	6.5	119	39.5	75	17.4	4.7	15	1.176
54	"	15	33	8.5	119	34.0	68	16.4	5.6	11	1.041
64	"	16	33	14.6	119	13.1	52	16.4	5.7	52	1.716
72	"	16	33	18.9	119	3.8	43	17.0	5.0	33	1.519
81	"	16	33	27.6	118	45.3	23	18.1	3.8	9	0.954
84	"	16	33	32.4	118	36.4	17	20.1	1.8	8	0.903
92	"	16	33	36.0	118	26.6	7	20.8	1.0	9	0.954
93	"	16	33	39.2	118	20.0	2	17.5	4.3	48	1.681
273	Aug.	14	33	33.5	118	17.5	4	20.9	1.8	2	0.301
283	"	15	33	41.0	118	22.0	2	19.6	3.0	4	0.602
284	"	15	33	41.0	118	22.0	2	19.6	3.0	4	0.602
288	"	15	33	39.0	118	31.5	8	19.5	3.1	2	0.301
289	"	15	33	39.0	118	31.5	8	19.5	3.1	3	0.477
293	"	15	33	36.0	118	40.0	17	18.4	4.2	4	0.602
294	"	15	33	36.0	118	40.0	17	18.4	4.2	4	0.602
298	"	15	33	33.0	118	49.0	24	20.1	2.6	3	0.477
299	"	15	33	33.0	118	49.0	24	20.1	2.6	2	0.301
303	"	15	33	30.5	118	58.0	35	18.4	4.3	12	1.079
304	"	15	33	30.5	118	58.0	35	18.4	4.3	10	1.000
308	"	15	33	26.0	119	10.5	43	17.4	5.4	16	1.204
309	"	15	33	26.0	119	10.5	43	17.4	5.4	15	1.176
357	Nov.	7	33	37.8	118	35.8	11	17.9	1.9	2	0.301
358	"	7	33	37.8	118	35.8	11	17.9	1.9	2	0.301
362	"	7	33	34.0	118	42.0	17	18.3	1.6	12	1.079
363	"	7	33	34.0	118	42.0	17	18.3	1.6	6	0.778
367	"	7	33	30.8	118	47.7	27	18.2	1.7	7	0.845
368	"	7	33	30.8	118	47.7	27	18.2	1.7	5	0.699
372	"	7	33	22.8	119	0.9	37	17.2	2.8	1	0.000
373	"	7	33	22.8	119	0.9	37	17.2	2.8	1	0.000
377	"	7	33	18.5	119	8.0	46	17.2	2.9	3	0.477
378	"	7	33	18.5	119	8.0	46	17.2	2.9	4	0.602

[1] R = reduction in temperature below that normal for the latitude and is determined by subtracting the observed temperature from the normal, N, where $N = -(3.35+0.175x) \cos (30t - 69°) + 21.30 - 0.72x$ where $t = 1$ for Jan. 15, 2 for Feb. 15, 3 for Mar. 15, etc., and where x = latitude in degrees minus 30°. The characteristic of the Logarithm is *minus* 1 for all entries of volumes less than 1. For further explanation see McEwen (1919, p. 347, equation 39.)

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Haul	Date		Latitude		Longitude		Distance from Pt. Fermin in nautical miles	Temperature		Phytoplankton	
								Observed	R	Volume	Log V
382	Nov.	7	33	15.0	119	13.0	52	17.0	3.1	5	0.699
386	"	7	33	15.0	119	13.0	52	17.0	3.1	1	0.000
387	"	7	33	15.0	119	13.0	52	17.0	3.1	1	0.000
388	"	8	33	10.5	119	30.5	65	15.8	4.3	4	0.602
389	"	8	33	10.5	119	30.5	65	15.8	4.3	3	0.477
396	"	8	33	6.2	119	38.0	75	15.8	4.3	2	0.301
397	"	8	33	6.2	119	38.0	75	15.8	4.3	3	0.477
398	"	8	33	6.2	119	38.0	75	15.8	4.3	2	0.301
402	"	8	33	1.9	119	45.6	81	16.5	3.5	2	0.301
403	"	8	33	1.9	119	45.6	81	16.5	3.5	1	0.000
407	"	8	32	57.6	119	53.1	88	17.8	2.4	2	0.301
408	"	8	32	57.6	119	53.1	88	17.8	2.4	2	0.301
409	"	8	32	53.3	120	0.7	94	17.8	2.5	1	0.000
410	"	8	32	53.3	120	0.7	94	17.8	2.5	2	0.301
417	"	8	32	49.0	120	8.0	104	17.8	2.5	1	0.000
418	"	8	32	49.0	120	8.0	104	17.8	2.5	2	0.301
	1918										
419	Jan.	4	33	39.0	118	24.4	4	15.7	0.4	1	0.000
420	"	4	33	39.0	118	24.4	4	15.7	0.4	0.25	1.398
423	"	4	33	35.1	118	35.5	14	16.6	-0.5	1	0.000
424	"	4	33	35.1	118	35.5	14	16.6	-0.5	1	0.000
427	"	4	33	32.0	118	46.8	23	16.2	0.0	1	0.000
428	"	4	33	32.0	118	46.8	23	16.2	0.0	1	0.000
430	"	4	33	28.3	118	57.9	35	15.5	0.7	5	0.699
433	"	4	33	26.0	119	4.7	40	14.6	1.6	1	0.000
435	"	4	33	26.0	119	4.7	40	14.6	1.6	0.25	1.398
437	"	4	33	20.3	119	14.1	49	14.3	2.1	1	0.000
438	"	4	33	20.3	119	14.1	49	14.3	2.1	1	0.000
440	"	5	33	8.6	119	22.0	58	14.2	2.4	2	0.301
441	"	5	33	8.6	119	22.0	58	14.2	2.4	3	0.477
443	"	6	33	7.5	119	31.0	65	14.5	1.9	2	0.301
444	"	6	33	7.5	119	31.0	65	14.8	1.6	2	0.301
446	"	6	33	4.5	119	36.5	71	14.7	1.8	1	0.000
447	"	6	33	4.5	119	36.5	71	14.7	1.8	1	0.000
449	"	6	33	2.0	119	40.8	77	14.6	1.9	1	0.000
450	"	6	33	2.0	119	40.8	77	14.6	1.9	1	0.000
452	"	6	32	58.0	119	45.5	81	15.2	1.4	0.25	1.398
453	"	6	32	58.0	119	45.5	81	15.1	1.5	0.5	1.699
455	"	6	32	56.5	119	51.0	87	15.1	1.5	0.5	1.699
456	"	6	32	56.5	119	51.0	87	15.1	1.5	0.5	1.699
461	"	6	32	50.5	120	0.0	96	15.1	1.6	1	0.000
462	"	6	32	50.5	120	0.0	96	15.1	1.6	1	0.000
464	"	6	32	47.7	120	5.3	100	15.6	1.1	1	0.000
465	"	6	32	47.7	120	5.3	100	15.6	1.1	1	0.000
467	"	6	32	44.5	120	10.5	106	15.4	1.4	1	0.000
468	"	6	32	44.5	120	10.5	106	15.4	1.4	1	0.000
470	"	6	32	42.0	120	15.5	112	15.6	1.2	0.5	1.699
471	"	6	32	42.0	120	15.5	112	15.6	1.2	0.5	1.699
473	Feb.	6	33	43.4	118	26.2	2	13.4	1.4	2	0.301

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Haul	Date		Latitude		Longitude		Distance from Pt. Fermin in nautical miles	Temperature		Phytoplankton	
								Observed	R	Volume	Log V
474	Feb.	6	33	43.4	118	26.2	2	13.4	1.4	1	0.000
476	"	6	33	38.4	118	37.3	11	14.1	0.8	2	0.301
477	"	6	33	38.4	118	37.3	11	14.1	0.8	1	0.000
479	"	6	33	33.9	118	47.5	24	14.4	0.6	1	0.000
480	"	6	33	33.9	118	47.5	24	14.4	0.6	1	0.000
482	"	6	33	29.8	118	56.7	31	14.5	0.5	0.5	1.699
483	"	6	33	29.8	118	56.7	31	14.9	0.1	0.5	1.699
485	"	6	33	24.6	119	6.7	40	15.0	0.1	0.5	1.699
487	"	6	33	19.0	119	16.3	49	14.0	1.2	4	0.602
488	"	6	33	19.0	119	16.3	49	14.0	1.2	5	0.699
490	"	7	33	11.0	119	28.0	65	12.4	2.9	4	0.602
491	"	7	33	11.0	119	28.0	65	12.4	2.9	5	0.699
493	Mar.	15	33	43.6	118	26.3	2	14.8	0.0	6	0.778
494	"	15	33	43.6	118	26.3	2	14.8	0.0	7	0.845
496	"	15	33	39.3	118	35.7	11	14.9	0.0	4	0.602
497	"	15	33	39.3	118	35.7	11	14.9	0.0	5	0.699
499	"	15	33	35.2	118	45.2	21	15.9	−1.0	5	0.699
500	"	15	33	35.2	118	45.2	21	15.9	−1.0	6	0.778
502	"	15	33	30.5	118	54.9	31	15.6	−0.5	6	0.778
503	"	15	33	30.5	118	54.9	31	15.6	−0.5	5	0.699
505	"	16	33	25.0	119	6.3	40	13.6	1.5	8	0.903
506	"	16	33	25.0	119	6.3	40	13.6	1.5	10	1.000
508	"	16	33	20.8	119	12.4	46	13.3	1.9	6	0.778
509	"	16	33	20.8	119	12.4	46	13.3	1.9	8	0.903
511	"	16	33	10.9	119	24.3	61	13.8	1.5	21	1.322
512	"	16	33	10.9	119	24.3	61	13.8	1.5	15	1.176
514	"	17	33	9.3	119	27.5	65	13.8	1.5	15	1.176
515	"	17	33	9.3	119	27.5	65	13.8	1.5	10	1.000
517	May	22	33	34.0	118	26.0	2	16.9	1.5	21	1.322
518	"	22	33	34.0	118	26.0	2	16.9	1.5	20	1.301
520	"	22	33	40.0	118	35.5	11	17.0	1.5	5	0.699
521	"	22	33	40.0	118	35.5	11	17.0	1.5	5	0.699
523	"	22	33	36.0	118	45.2	21	16.4	2.1	19	1.279
524	"	22	33	36.0	118	45.2	21	16.4	2.1	3	0.477
526	"	22	33	32.0	118	54.8	31	16.6	2.0	15	1.176
527	"	22	33	32.0	118	54.8	31	16.6	2.0	19	1.279
529	"	22	33	26.0	119	4.5	40	15.8	2.8	34	1.531
530	"	22	33	26.0	119	4.5	40	15.8	2.8	31	1.491
532	"	23	33	20.9	119	12.8	49	14.7	4.0	30	1.477
533	"	23	33	20.9	119	12.8	49	14.7	4.0	21	1.322
535	"	23	33	11.5	119	21.7	58	14.2	4.7	12	1.079
537	"	24	33	9.7	119	31.9	65	12.9	6.3	21	1.322
538	"	24	33	9.7	119	31.9	65	12.9	6.3	21	1.322
540	"	24	33	5.5	119	38.8	75	13.7	5.3	40	1.602
541	"	24	33	5.5	119	38.8	75	13.7	5.3	38	1.580
543	"	24	33	2.8	119	43.5	79	13.6	5.5	30	1.477
544	"	24	33	2.8	119	43.5	79	13.6	5.5	58	1.763
546	"	24	32	59.1	119	49.7	85	13.2	5.9	29	1.462
547	"	24	32	59.1	119	49.7	85	13.2	5.9	24	1.380

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Haul	Date		Latitude		Longitude		Distance from Pt. Fermin in nautical miles	Temperature		Phytoplankton	
								Observed	R	Volume	Log V
549	May	24	32	56.0	119	55.0	91	13.2	5.9	9	0.954
550	"	24	32	56.0	119	55.0	91	13.2	5.9	3	0.477
552	June	27	33	44.0	118	26.0	2	20.2	0.5	3	0.477
553	"	27	33	44.0	118	26.0	2	20.3	0.5	2	0.301
555	"	27	33	42.4	118	38.4	15	19.3	1.5	3	0.477
556	"	27	33	42.4	118	38.4	15	19.3	1.5	3	0.477
558	"	27	33	40.8	118	51.2	22	19.3	1.5	5	0.699
559	"	27	33	40.8	118	51.2	22	19.3	1.5	5	0.699
564	"	28	33	24.4	119	6.7	40	17.8	3.2	6	0.778
565	"	28	33	24.4	119	6.7	40	17.8	3.2	8	0.903
567	"	28	33	18.3	119	12.9	49	17.3	3.5	6	0.778
568	"	28	33	18.3	119	12.9	49	17.3	3.5	10	1.000
570	"	28	33	10.0	119	23.0	61	16.0	5.2	22	1.342
571	"	28	33	10.0	119	23.0	61	16.0	5.2	39	1.591
573	"	29	33	10.6	119	31.5	65	15.6	5.6	25	1.398
574	"	29	33	10.6	119	31.5	65	15.6	5.6	25	1.398
576	"	29	33	8.0	119	36.8	68	16.5	4.8	8	0.903
577	"	29	33	8.0	119	36.8	68	16.5	4.8	12	1.079
579	"	29	33	4.1	119	42.2	75	16.3	5.0	21	1.322
580	"	29	33	4.1	119	42.2	75	16.3	5.0	7	0.845
582	"	29	33	2.8	119	47.5	82	16.6	4.8	9	0.954
583	"	29	33	2.8	119	47.5	82	16.6	4.8	12	1.079
585	"	29	33	0.2	119	52.8	88	16.0	5.4	6	0.778
586	"	29	33	0.2	119	52.8	88	16.0	5.4	13	1.114
588	"	29	32	57.6	119	58.1	92	15.8	5.5	10	1.000
589	"	29	32	57.6	119	58.1	92	15.8	5.5	8	0.903
591	"	29	32	55.0	120	3.4	98	15.7	5.7	10	1.000
592	"	29	32	55.0	120	3.4	98	15.7	5.7	23	1.362
594	"	29	32	52.4	120	8.7	104	16.1	5.4	9	0.954
595	"	29	32	52.4	120	8.7	104	16.1	5.4	7	0.845
597	"	29	32	49.8	120	14.0	108	16.4	5.1	8	0.903
598	"	29	32	49.8	120	14.0	108	16.4	5.1	14	1.146
600	"	29	32	47.2	120	19.3	113	16.5	5.0	9	0.954
601	"	29	32	47.2	120	19.3	113	16.5	5.0	14	1.146
603	"	29	32	44.6	120	20.6	117	16.6	4.9	9	0.954
604	"	29	32	44.6	120	20.6	117	16.6	4.9	7	0.845
606	"	29	32	42.0	120	30.0	123	16.6	4.9	6	0.778
607	"	29	32	42.0	120	30.0	123	16.6	4.9	7	0.845

Two important sources of error must be mentioned. Large manipulative errors arise while making the collections, the most important being due to the resistance of the net. In order to prevent its tearing, it is necessary to run the hoisting engine at lowest speed. Although no difficulty is had in doing so when the sea is smooth, in the usual high sea, the surging of the boat produces a variable strain on net and engine, and not infre-

quently is the engine thereby stopped several times during a single haul. At such times, the boat, falling into the trough of the sea, generates a current that tends to flow through the net from peak to orifice, and so to empty it of whatever may have been caught. It is evident that the error so caused is large, although even its approximate magnitude can not be estimated.

An apparatus devised by the former mechanician of the Scripps Institution, James Ross, for eliminating this error, consists essentially in a combination net and float. The apparatus is lowered to the desired depth by cable and then released, the vertical haul from there to the surface being due to the buoyancy of the float. This apparatus, though still in an experimental stage, was used during July 1917, and to some extent later.

The second source of important error is natural rather than manipulative. Collections vary in the proportional number of individuals of the different species caught, and some species, upon settling, pack closer than others. Thus of two collections each containing the same amount of organized food stuffs, but of which one consists primarily say of *Chaetocerous criophilum* and the other of *Nitzchia seriata*, the latter will occupy a smaller volume upon settling than the former. A third collection, consisting primarily of dinoflagellates, will occupy a still smaller volume, although it may contain the greatest amount of organized food-stuff of the three. The magnitude of the error due to this cause is unknown, but it seems likely that it is less than the manipulative one above mentioned.

STATISTICAL METHODS EMPLOYED

In handling the data statistically, a method of successive approximation to group averages, supplemented by that of simple linear correlation, is used. The latter is well known and needs no further mention, and the former, though new, is fully described elsewhere (McEwen and Michael, 1919). On one point only does additional comment seem necessary, namely, in justifying the use of geometric rather than arithmetic mean.

Space forbids discussing fully the relative merits of these two means in biological statistics. There has been and still is much confused thinking on the subject, due primarily to failure in distinguishing between a law describing the relation to each other of repeated measurements of the same thing, and a law describing the relation to each other of single measurements of many things of the same kind. For example, in the case of one

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thousand measurements of the height of one fully grown man, this law is the well known, though frequently misused, Gaussian *law of error*; while, in the case of single measurements of the heights of one thusand men, this law is a *law of growth*. In some cases it may, and in this particular case does, resemble closely the Gaussian law of error from a mathematical point of view; and in such cases, it is advantageous to employ the system of reasoning based upon that law. But, it should not be forgotten that this reasoning does not strictly apply.

In general, the greater the asymmetry of the frequency curve, the less applicable is the Gaussian law of error and statistical methods based upon it. This seems self evident; yet the arithmetic mean continues to be used as the most reliable measure of the character in question, and the probable error continues to be applied even in cases of extreme asymmetry. This practice is due, of course, to convenience; it can be justified on no other ground. A more rational, if less convenient, procedure is to find some function of the measurement whose frequency distribution accords well with the Gaussian law of error, and deal with that function.

In the particular case at hand, this function is the logarithm. As shown by the accompanying histograms (figure 2), the frequency distribution of the volumes of phytoplankton is so highly asymmetrical as to be quite non-modal, whereas that of the logarithms of these volumes is nearly symmetrical, according well with the Gaussian law of error. The significance of this is that, since the arithmetic mean of the logarithms is the logarithm of the geometric mean of the volumes, volume of phytoplankton fluctuates in approximately constant ratio about the geometric mean. In other words, the magnitude of variation in volume of phytoplankton is not independent of, but approximately proportional to, that volume, and the geometric mean is the average in which these variations are compensatory.

A STUDY IN CORRELATION

VOLUME OF PHYTOPLANKTON, SEASON, AND DISTANCE FROM THE COAST

The one hundred seventy-four collections concerned in this investigation are distributed over the months of July, August, and November 1917, and January, February, March, May, and June 1918. The variation from month to month in volume of phytoplankton is shown in table II.

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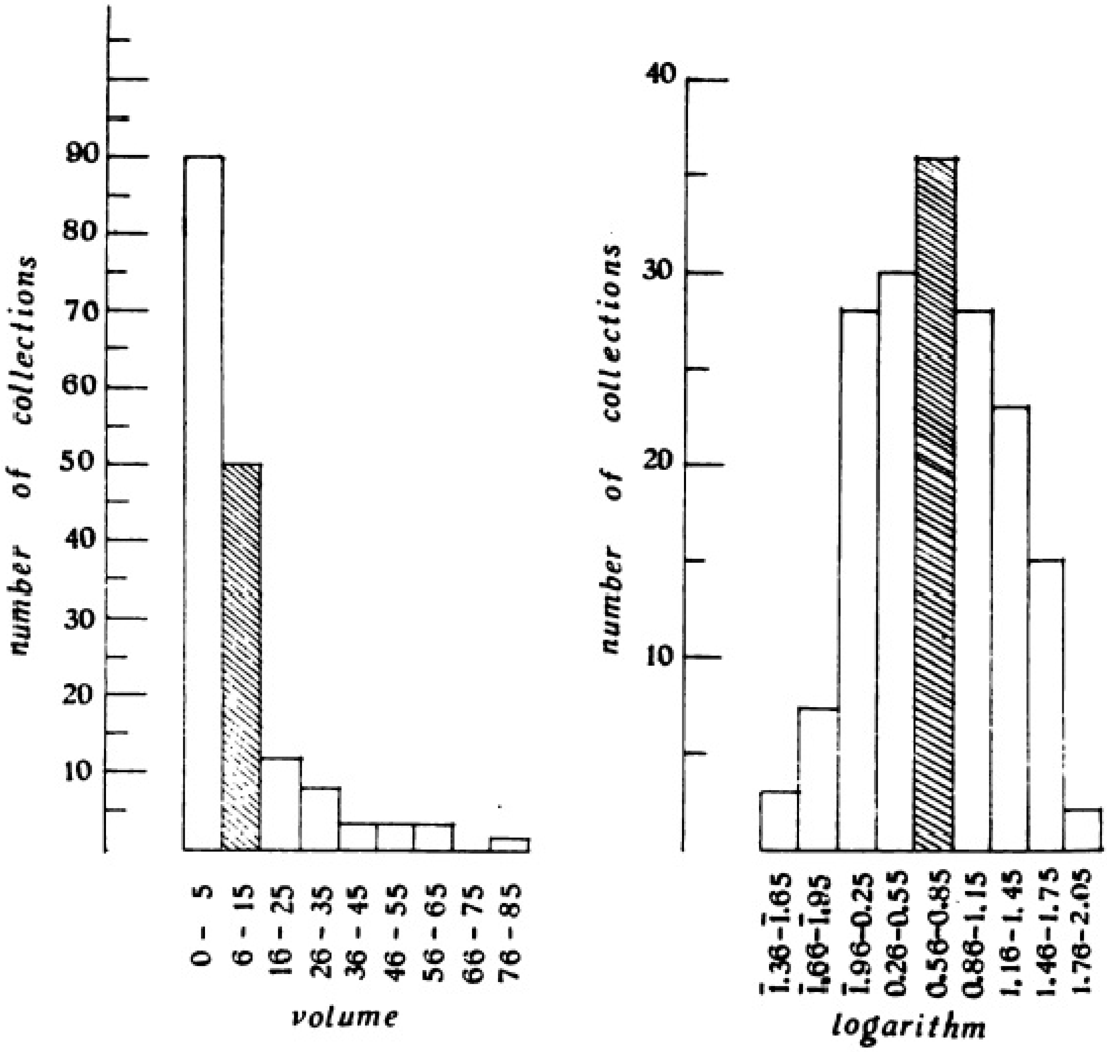


FIGURE 2. Histograms showing distribution of volumes of phytoplankton and their logarithms, the position of the averages (10.29 cc. and 0.685 cc.) being indicated by cross hatching. Ordinate = number of collections; abscissa = class interval.

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TABLE II. SEASONAL VARIATION IN VOLUME OF PHYTOPLANKTON

Month	Number of Collections	Average Volume of Phytoplankton Arithmetic mean	Geometric mean
July, 1917	16	33.3 cc.	13.9 cc.
Aug. 1917	13	6.2	5.0
Nov. 1917	26	3.0	2.3
Jan. 1918	31	1.2	0.8
Feb. 1918	13	2.1	1.5
Mar. 1918	16	8.6	7.7
May 1918	23	22.1	13.3
June 1918	36	10.9	8.8

Beginning with the maximum in July 1917, Table II indicates a rapid decrease at first and then a more gradual decrease until the minimum was reached in January 1918. Thereafter, the volume increased, slowly at first, and more rapidly later, until a second maximum was attained in May 1918. Although these data are quite inconclusive, the relation between the two maxima suggests a greater production of phytoplankton during 1917 than during 1918, and possibly a shift in the period of the maximum in the two years.

In order to ascertain the relation, if any, between volume of phytoplankton and distance from the coast, the data in Table I were arranged in order of increasing distance, and segregated, somewhat arbitrarily, into six groups. The first group consists of thirty-four collections scattered between two and seventeen miles from the coast. The average volume of phytoplankton obtained, together with that pertaining to each of the remaining five groups is given in Table III.

TABLE III. VOLUME OF PHYTOPLANKTON AND DISTANCE FROM THE COAST

Group	Number of Collections	Distance from coast in nautical miles Extremes	Average	Volume of phytoplankton Arithmetic Mean	Geometric Mean
1	34	2-17	8.5	6.0 cc.	3.4 cc.
2	26	21-37	27.4	5.7	3.5
3	31	40-58	46.7	10.9	5.3
4	31	61-77	68.5	12.8	7.3
5	29	79-96	86.9	17.3	5.6
6	23	98-123	107.7	8.3	5.0

Table III shows that volume of phytoplankton, as indicated by the geometric means, increased from a minimum nearest the coast to a maximum about seventy miles off, and then decreased with further increase in distance. Judging from the arithmetic means, however, this relation may not be significant, for they indicate a minimum not nearest the coast, but about thirty miles from it, and a maximum at a distance of about eighty-five

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instead of seventy miles from it. Although the geometric mean is the more reliable of the two measures, the relation indicated by both should be essentially the same. That it is not, points toward an uneven distribution of collections with respect to season, and emphasizes the need of correcting for the effect of season.

This correction is made by the method of successive approximation to group averages (McEwen and Michael, 1919), the initial equations and their solutions being given at the end of this paper. When the geometric means are corrected in this way to what they most probably would have been had all collections been made during May 1918, they become the following:

12.8 cc. for group 1.
13.0 cc. for group 2.
13.6 cc. for group 3.
14.0 cc. for group 4.
13.3 cc. for group 5.
13.4 cc. for group 6.

Correction for the effect of season, therefore, has not altered significantly the relation originally indicated: an increase is still evident from a minimum nearest shore to a maximum about seventy miles off. A slight increase, instead of a decrease, farthest seaward is suggested, but it is so slight as probably to be accidental. Supporting this interpretation is the fact that, when each observed volume is corrected for the effect of season and the regression coefficient determined for each of the six groups, each corroborates the evidence furnished by the averages, except for the fifth and sixth groups, where the coefficient shows a decrease in volume of phytoplankton with an increase in distance from the coast. Each regression coefficient, of course, pertains directly to the logarithms of the volumes and is the average change in the logarithm corresponding to an increase of one mile in distance from the coast. Expressed in terms of the volumes themselves, the antilogarithm of each regression coefficient is the common ratio, or average quantity by which each volume is multiplied to equal that one mile further from the coast. The six coefficients, expressed as common ratios, are:

1.012 for group 1
1.037 for group 2
1.025 for group 3
0.949 for group 4
0.973 for group 5
0.990 for group 6.

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Evidently some influence associated with distance from the coast is responsible for this variation in volume of phytoplankton, and upwelling water seems the most probable. Although upwelling occurs all along the coast, it is most pronounced at those points where the transition from shallow to deep water is most abrupt. This is established by McEwen (1916). Reference to plates 1 and 2 of his report shows, in the region here concerned, closest approach of the hundred meter contour to the coast between Point Fermin and Point Vincente, between Point Dume and Point Hueneme, and between Santa Barbara and Point Conception. Within these three localities upwelling, on the whole, is most pronounced between Santa Barbara and Point Conception, and least pronounced between Point Fermin and Point Vincente. If this water, together with that upwelling about the various Channel Islands, is carried southward as indicated by isotherms and isohalines (McEwen, 1916, pls. 6 and 10 especially), its amount within the areas here investigated might well be such as to account for the observed variation in volume of phytoplankton. In other words, study of the accompanying map in the light of localities of pronounced upwelling water and its probable direction of flow, suggests that, at any particular time, quantity of phytoplankton was greatest at that distance from the coast where amount of upwelled water was greatest.

CORRELATIONS BETWEEN VOLUME OF PHYTOPLANKTON AND TEMPERATURE

As already stated, one of the effects of upwelling water is to reduce both the surface temperature and salinity. This, of course, changes the density of the water and gives rise to a convective circulation which, aided by diffusion, tends to offset the reduction in salinity and to make it uniform over the entire region. The process of conduction likewise tends to offset the reduction in temperature, but this process is much slower than that of convection, whence the effect of upwelling water upon temperature is more persistent than is that upon salinity. It follows that if the amount of upwelled water within the areas investigated was at a minimum nearest shore and increased to a maximum about seventy miles off, as above suggested, the surface temperatures, when corrected for the effect of season, should indicate this.

This correction was made, as before, by the method of successive approximation to group averages, the solution being given at the end of this paper. The resulting averages, cor-

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rected to the month of May 1918, together with the corresponding distances from the coast and volumes of phytoplankton, are given in table IV.

TABLE IV. RELATION OF TEMPERATURE AND VOLUME OF PHYTOPLANKTON TO DISTANCE FROM THE COAST, EACH CORRECTED FOR THE EFFECT OF SEASON

		DISTANCE FROM COAST IN NAUTICAL MILES		VOLUME OF PHYTOPLANKTON		TEMPERATURE	
Group	Number of collections	Extremes	Average	Geometric mean	Common ratio	Average	Regression coefficient
1	84	2-17	8.5	12.8 cc.	1.012	16.21°c.	—0.008
2	26	21-37	27.4	13.0	1.037	16.06	—0.075
3	31	40-58	46.7	13.6	1.025	14.64	—0.054
4	31	61-77	68.5	14.0	0.949	13.85	+0.004
5	29	79-96	86.9	13.3	0.973	14.14	+0.012
6	23	98-123	107.7	13.4	0.990	14.39	+0.007

Table IV shows that, while volume of phytoplankton increased from a minimum nearest shore to a maximum about seventy miles off, the temperature decreased from a maximum to a minimum. Comparison of the common ratios and regression coefficients further shows that, within each of the six areas, an increase in volume of phytoplankton is accompanied, on the average, by a decrease in temperature, and a decrease in volume by an increase in temperature. In other words, Table 4 suggests a strong negative correlation between volume of phytoplankton and temperature, and points clearly toward upwelling water as an important cause of the observed variation in volume of phytoplankton.

Testing this indication by correcting each temperature and volume of phytoplankton entered in Table I for season, and running a correlation between the corrected values, or rather between the corrected temperatures and the logarithms of the corrected volumes, gives —0.4596 ±0.033[2] as the coefficient of correlation. Moreover, superimposing the correction for distance

[2] Two formulae are in use for computing the probable error of a correlation coefficient. That employed in this paper is

$$\text{P. E.} = \frac{0.6745\,(1-r^2)}{\sqrt{N\,(1+r)}}$$

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from the coast, i.e., correcting each observed temperature and volume of phytoplankton not only to the month of May 1918, but also to a distance of 46.7 miles from the coast, reduces the correlation coefficient by 0.2099 ± 0.054 to —0.2597 ± 0.042. In other words, the magnitude of the correlation between volume of phytoplankton and temperature is only about half attributable to influences associated with distance from the coast.

The significance of this is evident. Inshore currents are highly complex and variable, and, since the precise direction of flow of upwelled water depends upon these currents, its distribution within the six areas investigated must likewise have been highly complex and variable. Classification of observations with respect to distance from the coast is therefore an index only to the most prevalent or average distribution of upwelled water over a considerable period of time. The relation of temperature to upwelled water, on the other hand, is quite independent of how much the distribution of that water may vary, whence a portion of its correlation with phytoplankton should likewise be independent of such variation.

By eliminating the effect upon temperature and phytoplankton of those influences associated with season and distance from the coast, i.e., by correcting each observation to a constant month and distance, and computing the temperature-phytoplankton correlation coefficient pertaining to each of the six areas, this interpretation is put to an empirical test. For, if correct, the coefficient should be greatest relative to those areas where amount of upwelled water, as indicated by the temperature, was most variable, namely, nearest shore and farthest seaward. The six coefficients are:

—0.5104 for group 1.
—0.2329 for group 2.
—0.0072 for group 3.
—0.1183 for group 4.
—0.2029 for group 5.
—0.3299 for group 6.

Finally, McEwen (1919) has pointed out that amount of upwelling water increases from a minimum in winter to a maximum in summer. This is evident in the data here considered, for the average reduction in temperature below that normal for the latitude is 4.18° C. for the eighty-eight observations made during the months of July and August 1917, and May and June 1918, while it is only 1.61° C. for the eighty-six observations made during the months of November 1917 and January, Feb-

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ruary, and March 1918. Accordingly, if the negative correlation between temperature and phytoplankton is consequent upon upwelling, the coefficient computed from the summer data should significantly exceed that computed from the winter data. Such proves true, the former coefficient being —0.593 ± 0.037 and the later only —0.096 ± 0.069, or, when seasonal effects are eliminated by correcting each observation to May 1918, the former coefficient becomes —0.602 ± 0.036, and the latter —0.215 ± 0.063.

A PROBABLE LAW OF RELATIONSHIP

VOLUME OF PHYTOPLANKTON AN EXPONENTIAL FUNCTION OF THE TEMPERATURE REDUCTION

The foregoing evidence gives good support to the supposition that quantity of phytoplankton increases with amount of upwelled water. Indeed, the evidence is so consistent as to make it advisable to determine the relation between the two more precisely in an attempt to isolate from the causal complex underlying phytoplankton production the law by which this production is related to upwelling water. In undertaking this, two methods are possible: the law may be deduced from general principles; or, by means of the method of successive approximation to group averages, it may be determined inductively from the data themselves. The latter method is here employed, not because it is more meritorious than the former, but because lack of sufficiently well established quantitative principles affords an inadequate basis for rigorous deduction.

Restricting attention to the eighty-eight collections made during the summer months because of the small volume of phytoplankton obtained and the slight amount of upwelling during the winter, the form of equation relating volume of phytoplankton to the temperature reduction may be approximated by means of the *slope* method of group averages (McEwen and Michael, 1919, p. 111). Preliminary to the use of this method, however, it is desirable briefly to consider; first, the nature of the data with reference to grouping the causes of phytoplankton production and so fixing the most important variables involved; and, second, since reduction in temperature below that normal for the latitude is used as a measure of upwelling, the relation between this reduction and the upwelling velocity.

Obviously, the causes of phytoplankton production may be classified into two groups: those associated primarily with time,

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and those associated primarily with space. With respect to time, all collections were made by vertical hauls from two hundred meters to the surface so that whatever diurnal variation may have existed in the vertical distribution of phytoplankton could not have effected, significantly, the volume collected, irrespective of the time of day the collections were made. Further, all collections, during any one month, were restricted to an interval of three days at the most. Doubtless this means some change in production and, consequently, some difference between the quantity of phytoplankton actually obtained at the various stations and the quantity that would have been obtained had all collections been made simultaneously. But it is evident that this difference is slight, whence it seems that the only important element of time is month. With respect to space, all collections were confined to a narrow strip of water approximately perpendicular to the coast, and the foregoing evidence demonstrates that temperature of the water is a good index to the variability in quantity of phytoplankton from place to place within that strip. Month and temperature are thus selected as the most important indices to the influences underlying variability in the volume of phytoplankton collected. It is desired, however, to isolate from each other the effect of that group of influences associated with upwelling water from the effect of that group not so associated, whence the reduction in temperature is substituted for the temperature proper, and corrections computed for the effect of variation from month to month.

The relation of temperature reduction to velocity of upwelling is shown by McEwen (1919, tables 11 and 12). Though one is not a linear function of the other, it appears from these tables that, during the summer months (May, June, July, and August) and within the limiting values ($0°5 < R < 6.3°$) of the data here considered, the linear equation

$$R = 0.1825W - 1.0 \qquad (1)$$

represents the relation between the two near the source of upwelling within an error of 0.2° C, where R = temperature reduction in degrees centigrade, and W = velocity of upwelling in meters per month. For example, the surface reductions which, according to McEwen's estimate, correspond to velocities of 10 and 40 meters per month, are 0.99° C. and 0.45° C. respectively: equation (1) gives 0.82° C. and 6.30° C. Although no

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further use is made of equation (1) it enables one to visualize the relation.

In applying the *slope* method, the observed volumes of phytoplankton are first arranged in ascending order of the magnitude of the temperature reduction, and segregated into three groups of twenty-seven, twenty-eight, and thirty-three observations respectively, according to whether *R* lay between 0.5° C. and 3.2° C., 3.5° C. and 5.1° C., or 5.2° C. and 6.3° C. The average (geometric mean) volume of phytoplankton in each of the three groups is then corrected for the effect of month by reducing each (see Solution of Equations) to what it most probably would have been had all observations been made during May 1918. The end results are shown in Table V.

TABLE V. RELATION OF VOLUME OF PHYTOPLANKTON TO AMOUNT OF UPWELLED WATER MEASURED BY THE MAGNITUDE OF THE REDUCTION IN TEMPERATURE BELOW THAT NORMAL FOR THE LATITUDE

Group	Number of observations	Temperature reduction: Range	Temperature reduction: Average	Mean volume of phytoplankton: Observed	Mean volume of phytoplankton: Corrected to May 1918	Mean volume of phytoplankton: Computed by equation (2)	Mean volume of phytoplankton: Common ratio
1	27	0.5°—3.2°	2.044°	6.0 CC	10.2 CC	10.3 CC	1.34
2	28	3.5 —5.1	4.56	11.6	20.8	20.7	1.31
3	33	5.2 —6.3	5.61	20.3	27.6	27.7	1.30

$$\log V = 0.7637 + 0.1211\ R \text{ or } V = 5.804\ (1.32)^R \qquad (2)$$

This table shows that, when corrected to the month of May 1918, volume of phytoplankton increased, on the average, from 10.2 cc. to 20.8 cc. to 27.6 cc. as *R* increased from 2.044° C. to 4.56° C. to 5.61° C. If the logarithms of these volumes be plotted against the corresponding temperature reductions, they will be found to lie very nearly on a straight line whose equation (2) is that entered in the table. The accuracy of this relation is indicated by comparison of the values ascertained directly by the slope method with those computed by equation (2). It seems evident that such close agreement can not be entirely attributed to chance. Moreover, the common ratios show that, in group 1. volume of phytoplankton increased, on the average, 1.34 times for an increase of one degree in *R;* while, in group 2, it increased 1.31 times; and, in group 3, 1.30 times. Such consistency is highly improbable, regarded as mere coincidence, since each of

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the three ratios are determined independently of each other by the slope method, and since this method involves no assumption whatsoever concerning the nature of relation between volume of phytoplankton and reduction in temperature. Table V thus constitutes an inductive demonstration that, so far as the eighty-eight observations under consideration are concerned, volume of phytoplankton increases, on the average, in approximate geometric progression as reduction in temperature increases in arithmetic progression.

Agreement between observed and computed volumes for the two summer months, August 1917 and May 1918, are not satisfactory. The reason seems to be that the volume collected during August is slightly, if any, greater than the error inherent in its measurement; while, during May, the sea was rougher than during any other month thereby rendering the error due to surging of the boat a maximum. In spite of this, the common ratio determined from the August data is 1.85, while that determined from the May data is 1.13, making an average for the two months combined of 1.35; a value agreeing well with those entered in Table V.

Turning attention to the two remaining summer months, July 1917 and June 1918, it is found that, during July, a larger volume of phytoplankton was collected than during any other month, and that the combination floatnet was used, thereby eliminating the large collecting error due to surging; while during June, a greater number of collections were made than during any other month, and the sea was unusually smooth, reducing significantly the error due to surging even though the floatnet was not used. It seems, then, that the data for these two months are especially well adapted to the comparison of observed and computed volumes. The sixteen observations made during July 1917, and the thirty-six made during June 1918, were therefore arranged in order of the increasing magnitude of R, and segregated into four groups of four observations each for July, and nine each for June. Table VI gives the average temperature reduction for each group, and the corresponding observed and computed volumes of phytoplankton.

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TABLE VI. OBSERVED AND COMPUTED VOLUMES OF PHYTOPLANKTON FOR THE MONTHS OF JULY 1917 AND JUNE 1918

JULY 1917					JUNE 1918				
R	Observed		Computed		R	Observed		Computed	
	Log V	V	Log V	V		Log V	V	Log V	V
2.73°C.	1.123	13.3	1.127	13.4	1.88°C.	0.621	4.2	0.623	4.2
4.95	1.441	27.6	1.442	27.7	4.66	0.971	9.4	0.995	9.9
5.50	1.523	33.4	1.520	33.1	5.10	1.081	12.1	1.053	11.3
5.90	1.577	37.8	1.576	37.7	5.53	1.108	12.8	1.111	12.9
$\log V = 0.7403 + 0.1417R$					$\log V = 0.3716 + 0.1337R$				
$V = 5.50\ (1.39)^R$ (3)					$V = 2.35\ (1.36)^R$ (4)				

The agreement between observed and computed volumes shown by this table is surprisingly close, the greatest deviation being only 0.8 cc. Furthermore, the common ratios (see equations 3 and 4), 1.39 for July and 1.36 for June, agree remarkably well with the values, 1.30 to 1.34, ascertained by the slope method (Table V).

Considering all of the eighty-eight observations, the means of the observed volumes corresponding to each value of R are plotted in figure 3 along with the volumes cumputed by the equation

$$\text{Log } V = 0.7637 + 0.1211R - S \qquad (5)$$

which is equation (2) with the seasonal constant S subtracted to correct each volume from May 1918 to the month in which the observation was made. A good agreement between observed and computed volumes is seen, although not so good as for June and July taken separately.

Perhaps the most striking way of illustrating the relation between temperature reduction and volume of phytoplankton is to compute the former from the latter for each of the eighty-eight observations. This is accomplished by equation (5) transformed so as to give R as a function of V instead of V as a function of R, namely

$$R = 8.258\ (\log. V + S) - 6.306 \qquad (6)$$

Table VII shows the agreement between the values of R computed in this way, and those determined as in table I, here designated as observed.

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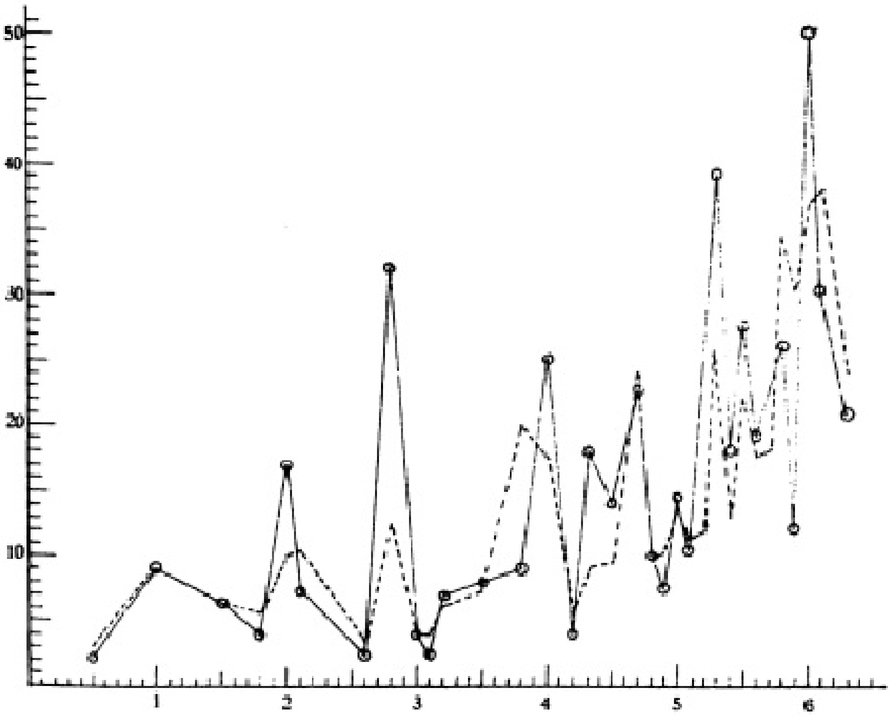


FIGURE 3. Relation between volume of phytoplankton in cc. (ordinate) and temperature reduction in degrees Centrigrade (abscissa) as shown by eighty-eight observations distributed over the months of July and August 1917 and May and June 1918. Solid line connects observed volumes: broken line connects volumes computed by equation (5), the general upward trend being due to *R* and the peaks and depressions to *S*.

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TABLE VII. COMPARISON OF OBSERVED VALUES OF R WITH THOSE COMPUTED FROM VOLUME OF PHYTOPLANKTON

Haul	O	C	O-C	Haul	O	C	O-C
F 12	6.1° C.	5.3° C.	+0.8° C.	540	5.3	6.9	—1.6
14	5.8	4.8	+1.0	541	5.3	6.7	—1.4
21	5.4	4.0	+1.4	543	5.5	5.9	—0.4
23	5.4	4.5	+0.9	544	5.5	8.2	—2.7
32	6.0	7.1	—1.1	546	5.9	5.8	+0.1
34	5.5	7.5	—2.0	547	5.9	5.1	+0.8
42	5.5	8.9	—2.4	549	5.9	1.6	+4.3
43	4.7	7.5	—2.8	550	5.9	—2.4	+8.3
52	4.7	2.8	+1.9	552	0.5	0.4	+0.1
54	5.6	1.7	+3.9	553	0.5	—1.0	+1.5
64	5.7	7.2	—1.5	555	1.5	0.4	+1.1
72	5.0	5.6	—0.6	556	1.5	0.4	+1.1
81	3.8	0.9	+2.9	558	1.5	2.3	—0.8
84	1.8	0.5	+1.3	559	1.5	2.3	—0.8
92	1.0	0.9	+.01	564	3.2	2.9	+0.3
93	4.3	6.9	—2.6	565	3.2	3.9	—0.7
273	1.8	0.6	+1.2	567	3.5	2.9	+0.6
283	3.0	3.1	—0.1	568	3.5	4.7	—1.2
284	3.0	3.1	—0.1	570	5.2	7.6	—2.4
288	3.1	0.6	+2.5	571	5.2	9.6	—4.4
289	3.1	2.0	+1.1	573	5.6	8.0	—2.4
293	4.2	3.1	+1.1	574	5.6	8.0	—2.4
294	4.2	3.1	+1.1	576	4.8	3.9	+0.9
298	2.6	2.0	+0.6	577	4.8	5.4	—0.6
299	2.6	0.6	+2.0	579	5.0	7.4	—2.4
303	4.3	7.0	—2.7	580	5.0	3.5	+1.5
304	4.3	6.3	—2.0	582	4.8	4.4	+0.4
308	5.4	8.0	—2.6	583	4.8	5.4	—0.6
309	5.4	7.8	—2.4	585	5.4	2.9	—0.3
517	1.5	4.6	—3.1	586	5.4	5.7	+2.5
518	1.5	4.4	—2.9	588	5.5	4.7	+0.8
520	1.5	—0.5	+2.0	589	5.5	3.9	+1.6
521	1.5	—0.5	+2.0	591	5.7	4.7	+1.0
523	2.1	4.2	—2.1	592	5.7	7.7	—2.0
524	2.1	—2.4	+4.5	594	5.4	4.4	+1.0
526	2.0	3.4	—1.4	595	5.4	3.5	+1.9
527	2.0	4.2	—2.2	597	5.1	3.9	+1.2
529	2.8	6.3	—3.5	598	5.1	5.9	—0.8
530	2.8	6.0	—3.2	600	5.0	4.4	+0.6
532	4.0	5.9	—1.9	601	4.5	5.9	—1.4
533	4.0	4.6	—0.6	603	4.9	4.4	+0.5
535	4.7	2.6	+2.1	604	4.9	3.5	+1.4
537	6.3	4.6	+1.7	606	4.9	2.9	+2.0
538	6.3	4.6	+1.7	607	4.9	3.5	+1.4

The probable error of a single observation, which, of course, means a single net haul, is $\pm\ 0.6745 \sqrt{\frac{385.49}{88.5}} = \pm\ 1.45°$ C. Though this reliability is not great, it is not bad considering the number and magnitude of errors inherent in the collecting of

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phytoplankton and in its volumetric measurement; and also that only one causal influence, or group of influences, other than upwelling, has been taken into account.

NATURE OF RELATION BETWEEN PHYTOPLANKTON AND TEMPERATURE REDUCTION SUGGESTED BY PRINCIPLES UNDERLYING PHOTOSYNTHESIS

Growth in green plants can not proceed more rapidly than the rate at which carbohydrates and proteins are synthesized, nor can it proceed less rapidly, since broadly interpreted the products of these syntheses constitute growth. Further, because both kinds of synthesis are necessary, growth presupposes both to take place at approximately proportional rates. Abnormality and death must otherwise ensue. Essentially this is Liebig's "Law of the Minimum," which stipulates that plant growth can not be more rapid than permitted by the food-stuff present in minimal quantity, irrespective of how abundant other needed food-stuffs may be. In the sea it is probable that the limiting materials are the nitrates required for protein synthesis, and, with reference to diatoms, the silica needed in the secretion of their frustules. Each of these substances occurs in exceedingly small quantity, although it is likely that this quantity increases with amount of upwelled water. Be this as it may, it is obvious that, at the height of phytoplankton production, these substances are present in sufficient quantity to permit rapid growth. Whence, since growth in these plants, especially in the diatoms, expresses itself primarily in propagation, it follows that an estimate either of the rate of photosynthesis or of the rate of protein synthesis is an estimate of the rate of propagation. The chemistry of protein synthesis, however, is so inadequately understood as to afford scarcely any basis for estimating its rate, and the chemistry of photosynthesis, though better understood, is rampant with speculation and hypothesis.

The first steps in the chemistry of photosynthesis are uncertainly known. Quoting from Green (1911, p. 748) who best summarizes the present extent of knowledge: "the first chemical change suggested is an interaction between carbon dioxide and water, under the influence of light acting through chlorophyll, which leads to the simultaneous formation of formaldehyde and hydrogen peroxide. The formaldehyde at once undergoes a process of condensation or polymerization by the protoplasm of the plastid, while the hydrogen peroxide is said to be decomposed into water and free oxygen . . . . ." However this may

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be, the hexose sugars, glucose and fructose, appear early, and it is well established (Brown and Morris, 1893) that they are produced through the hydrolytic cleavage (inversion) of cane sugar, though the manner in which cane sugar itself originates is subject to controversy. This cleavage of cane sugar typifies many of the chemical processes involved in photosynthesis. Indeed, according to Henderson (1913, p. 160): "Reactions of this type, in which carbohydrates, fats, proteins, and other substances take part, make up a very large, if not the largest fraction of all the processes of metabolism . . . . ." But the cleavage takes place only in the presence of an acid, and its velocity is proportional to the strength of the acid. In other words, the phenomenon is one of catalysis, and, since the strength of an acid is proportional to its dissociation, "the hydrogen-ions are the catalyzers, and the velocity of inversion is approximately proportional to the concentration of the hydrogen-ions present." (Jones, 1902, p. 456.)

This at once suggests that, under favorable conditions, rate of photosynthesis in aquatic plants may be directly proportional to the hydrogen-ion concentration of the water. Indeed, experiments by Blackman and Smith (1910) on the fresh water plants, Fontinalis, Elodea, and Ceratophyllum, point in this direction. These investigators found that rate of photosynthesis was directly proportional to the available carbon dioxide supply, which, of course, means that it varies directly with the hydrogen-ion concentration, although the experiments, being designed from a quite different point of view, do not justify a more precise statement. Again, experiments by Moore, Prideaux, and Herdman (1915), concerning the limitations of photosynthesis by algae in sea water, point in the same direction. These experiments, especially the first one, show that rate of photosynthesis decreased significantly as the hydrogen-ion concentration decreased, and, to quote (p. 257), that "photosynthetic action stops at the precise point where all the available bicarbonate has been converted into carbonate; and the hydrogen-ion concentration has then reached the suprisingly low value—$10^{-9.1}$." Though these experiments fall short of proof, they are very suggestive.

Turning again to chemistry, it is well known that, within physiological limits, velocity of chemical reaction increases with the temperature, sometimes trippling, but usually doubling, with an increase of 10° C. This characterizes a wide range of chemical phenomena, especially those resembling the processes taking

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place within the organism, such as the saponification of esters and cleavage of sugars. Moreover, Blackman (1905) and Blackman and Smith (1910), as well as other investigators, have found this to hold for the photosynthesis of both land and aquatic plants, the rate doubling for an increase of 10° C., providing the temperature be less than 27° C. Above this temperature secondary effects come into play, and the rate of photosynthesis, though initially according with expectation, decreases, and it appears that the higher the temperature, the greater and more rapid is this decrease.

It seems, then, that under similar conditions of illumination and during a season when phytoplankton is abundant, reasonable justification is had for writing

$$r = k H \times 2^{\left[\frac{t}{10}\right]} \qquad (7)$$

where r[3] = rate of propagation during a time interval $T_2—T_1$ conditioned as brief in comparison to the time required for marked seasonal change in production, where H = hydrogen-ion concentration of the water, where t = temperature of the water in degrees centigrade, and where k = a proportionality constant.

As stated on a previous page it is probable that upwelling brings to the surface the disintegration products of the carcasses of organisms continually accumulating upon the bottom of the sea, and that among these products is carbon dioxide. Several facts support this. First, Henderson (1913, p. 169) summarizes the evidence concerning the vertical distribution of carbon dioxide in the Mediterranean, Atlantic, North Sea, and Black Sea, and shows it to increase from surface to bottom. Second, although similar observations have not been made in

[3] The validity of equation (7), or of any equation expressing the relation between two or more of the variables concerned in photosynthesis, hinges upon the validity of certain conclusions of Blackman and Smith (1910). In their admirable endeavor to replace the concept of "optimal conditions" in photosynthesis by the more rational one of "interaction of limiting factors," they have not proven, as they seem to believe, that temperature is a limiting factor in the same sense that available light energy or carbon dioxide supply are. Obviously, if all available light energy be utilized at a certain rate of photosynthesis, this rate cannot be increased *under any conditions* save by supplying more light. The same cannot be said, as Blackman and Smith imply, when both the CO_2 and light energy are excessive, but constant, and temperature seems to be the limiting factor. For temperature has only a tonic or stimulative effect; it is in no sense consumed. Proper alteration of anything else having a similar tonic effect, such as increase in acidity, should increase the rate of photosynthesis even though the temperature remained unaltered, just as is the case in the inversion of cane sugar and similar phenomena. The experiments of Blackman and Smith, though noteworthy, are wholly inapplicable to this question, if, indeed, there be any question.

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the Pacific, Mayor (1919, p. 151) says: "I find that the CO_2 tension of the surface waters along the Pacific Coast of the United States is considerably higher than we would expect from its low temperature and much above that of the water farther off the Coast. Thus a P_H of 7.85 at 10.5° C. and a CO_2 tension of 5.4 ten-thousandths of an atmosphere were observed 54 miles off Golden Gate, San Francisco, on May 1, 1917; and somewhat similar conditions were seen off Vancouver in September, 1918". Third in the coastal regions of Southern California, a quite definite relation holds between the hydrogen-ion concentration and temperature reduction of the surface waters, at least during certain months. This is made evident by table VIII in which are entered a series of sixty-four P_H observations together with those computed by the equation

$$\text{Log}\,(H \times 10^9 - 6.17) = \log R - 0.0025 + 0.0246\,R \quad (8)$$

an equation which, though partly supported by theory, can not be established deductively in the present state of knowledge. Suffice the remark that, as implied in the above quotation from Moore, Prideaux, and Herdman (1915, p. 257), a plant, in withdrawing carbon-dioxide from the water, converts bicarbonate into carbonate and so decreases the hydrogen-ion concentration, whence this concentration at any particular time and place depends not only upon amount of upwelling but also upon amount of photosynthesis, and, of course, amount of plant and animal respiration, between the source of the upwelled water and place of observation.

Each observed value of the P_H entered in Table VIII was measured by the colorimetric method, cresol red being used as indicator; and each of the sixty-four water samples was taken at 8 a. m. during July 1919. Six were taken at La Jolla, where upwelling is slight; twenty at Summerland (near Santa Barbara, latitude 34° 25.0' N.), twenty-seven at Pt. Hueneme (latitude 34° 8.6' N.), and eleven at Arguello (about ten nautical miles north of Pt. Conception, latitude 34° 34.5' N.)

Table VIII shows a good agreement between observed and computed values of the P_H. The deviations indicate a probable error of about ±0.06 for a single observation, an accuracy much greater than expected since the error involved in measuring the P_H is approximately ±0.025.

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TABLE VIII. COMPARISON OF OBSERVED VALUES (O) OF P_H WITH THOSE COMPUTED (C) BY EQUATION (8)

R	$H \times 10^9$	P_H O.	P_H C.	P_H O-C
		La Jolla		
0				
0.3c	6.31	8.20	8.19	+0.01
0.3	7.08	8.15	8.19	−0.04
1.0	7.08	8.15	8.14	+0.01
0.4	6.31	8.20	8.18	+0.02
1.1	7.08	8.15	8.14	+0.01
1.1	7.08	8.15	8.14	+0.01
		Summerland		
3.4	15.85	7.80	8.00	−0.20
3.5	10.00	8.00	7.99	+0.01
2.7	10.00	8.00	8.03	−0.03
3.1	10.00	8.00	8.01	−0.01
2.7	10.00	8.00	8.03	−0.03
3.4	8.91	8.05	8.00	+0.05
2.8	10.00	8.00	8.02	−0.02
2.5	10.00	8.00	8.04	−0.04
2.3	10.00	8.00	8.06	−0.06
1.8	10.00	8.00	8.09	−0.09
2.4	10.00	8.00	8.05	−0.05
2.4	8.91	8.05	8.05	+0.00
2.4	8.91	8.05	8.05	+0.00
2.5	7.94	8.10	8.04	+0.06
2.5	7.94	8.10	8.04	+0.06
3.7	11.22	7.95	7.97	−0.02
5.2	11.22	7.95	7.88	+0.07
4.3	10.00	8.00	7.94	+0.06
4.3	7.94	8.10	7.94	+0.16
4.1	7.94	8.10	7.95	+0.15
		Pt. Hueneme.		
8.4	25.12	7.60	7.71	−0.11
7.4	22.39	7.65	7.76	−0.11
7.2	22.39	7.65	7.77	−0.12
7.2	17.75	7.75	7.77	−0.02
7.3	17.75	7.75	7.76	−0.01

R	$H \times 10^9$	P_H O.	P_H C.	P_H O-C
		Pt. Hueneme.		
6.8	19.96	7.70	7.79	−0.09
6.7	11.22	7.95	7.80	+0.15
6.2	11.22	7.95	7.83	+0.12
5.9	15.85	7.80	7.84	−0.04
6.8	22.39	7.65	7.79	−0.14
5.7	15.14	7.82	7.85	−0.03
6.1	15.14	7.82	7.83	−0.01
5.9	14.13	7.85	7.84	+0.01
5.9	14.13	7.85	7.84	+0.01
5.8	15.85	7.80	7.85	−0.05
5.2	12.59	7.90	7.88	+0.02
3.8	11.22	7.95	7.96	−0.01
5.6	17.75	7.75	7.86	−0.11
6.8	28.18	7.55	7.79	−0.24
8.4	14.13	7.85	7.71	+0.14
8.4	11.22	7.95	7.71	+0.24
9.6	28.18	7.55	7.65	−0.10
9.9	25.12	7.60	7.63	−0.03
6.2	25.12	7.60	7.83	−0.23
5.6	15.85	7.80	7.86	−0.06
5.9	28.18	7.55	7.84	−0.29
6.0	19.96	7.70	7.84	−0.14
		Arguello		
8.1	22.39	7.65	7.72	−0.07
8.2	15.85	7.80	7.72	+0.08
8.4	19.96	7.70	7.71	−0.01
8.4	17.75	7.75	7.71	+0.04
9.9	25.12	7.60	7.63	−0.03
9.9	19.96	7.70	7.63	+0.07
10.6	17.75	7.75	7.60	+0.15
9.5	15.85	7.80	7.65	+0.15
9.5	15.85	7.80	7.65	+0.15
9.0	28.18	7.55	7.68	−0.13
9.6	25.12	7.60	7.65	−0.05

If equation (8) expressed in its general form

$$H = A + KRe^{k_1 R} \qquad (9)$$

where $\log_{10} e^{k_1}$ is specified as 0.0246, be substituted into equation (7), the analytic equivalent of equations (2) follows. Making this substitution, and also introducing N-R, for t, where

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N = the temperature normal for the latitude, equation (7) becomes

$$r = kA + kKRe^{k_1R} \times 2^{\left(\frac{N-R}{10}\right)}$$

$$= A_1 + K_1R\ 10^{(0.0246R)} \times 2^{\left(\frac{N-R}{10}\right)} = A_1 + y \qquad (10)$$

$$\text{Log}_{10}y = \log K_1 + 0.0301N + \log R - 0.0055R$$
$$= \log C + \log R - 0.0055R \qquad (11)$$

where $\log C = \log K_1 + 0.0301N$ is nearly constant since, for any one month, N varies less than 0.3° C. between the southernmost and northernmost position at which collections were taken: and since the difference in N from month to month is taken account of in the seasonal correction made by the method of successive approximation. Whence

$$r = A_1 + CR\ (0.988)^R \qquad (12)$$

Considering the method of propagation, let m = number of cells living at the time T_1, P = number produced by the time T_2, where, as stipulated above (equation 7), $T_2 - T_1$ is small compared with the time required for marked seasonal change in production, n = number of generations between T_1 and T_2. Then, since the method of propagation is that of cell division

$$P_1 = 2m,\ n = 1$$
$$P_2 = 4m,\ n = 2$$
$$P_3 = 8m,\ n = 3$$

or, in general

$$P = 2^n m \qquad (13)$$

But all of the cells produced do not live. Assuming the number dying each generation to be proportional to the "population," an assumption which is justified by the logarithmic frequency curve (figure 2), if d = the proportion that die, and L = the number living at the time T_2,

$$L_1 = 2m\ (1-d),\ n = 1$$
$$L_2 = 4m\ (1-d)^2,\ n = 2$$
$$L_3 = 8m\ (1-d)^3,\ n = 3$$

or, in general

$$L = m\ (2-2d)^n \qquad (14)$$

From equation (12) $n = r\ (T_2-T_1) = (T_2-T_1)\ [A_1 + CR\ (0.988)^R] = A_2 + C_1R\ (0.988)^R$. Substituting this

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equivalent for n and $\frac{V}{v}$ for L into equation (14) where

V = volume of phytoplankton at the time T_2 and v = the average volume of one cell,

$$V = mv\ (2\text{-}2d)\ ^{A_2 + C_1 R}\ (0.988)^R \qquad (15)$$

Since the expression $(0.988)^R = 0.881$ when $R = 10°$ C. which exceeds by more than 3° C. the maximum value of R in the data here considered, an error of less than two per cent is introduced in C_1 by disregarding it. Whence, approximately, equation (15) is

$$V = mv\ (2\text{-}2d)\ ^{A_2 + C_1 R}$$

$$\text{Log } V = \log mv + A_2 \log (2\text{-}2d) + C_1 R \log (2\text{-}2d) \qquad (16)$$

which reduce to the form of equations (2) namely:

$$V = A'_3\ (C'_2)^R$$

$$\text{Log } V = A_3 + C_2\ R \qquad (17)$$

where $A_3 = \log A'_3 = \log mv + A_2 \log (2\text{-}2d)$, and $C_2 = \log C'_2 = C_1 \log (2\text{-}2d)$.

It is worthy of note that, in order to make up for the error introduced by neglecting the expression $(0.988)^R$, the common ratio C'_2 must decrease with an increase in R, and this proves actually to be the case (Table V). Moreover, given a value $C\bar{a}$ of C'_2 corresponding to any particular value $R\bar{a}$ of R, any other value of C'_2 is readily estimated, since, from equations (15) to (17), $C\bar{a} : C'_2 :: 1 : (0.988)\ ^{Ra - C}$. Putting $C\bar{a} = 1.32$, its value in equations (2), and $R\bar{a} = 4.18°$ C, the average reduction for the eighty eight observations upon which equations (2) are based, the estimated values of the three common ratios given in table 5 are: 1.356 against 1.34 for R = 2.044° C.: 1.314 against 1.31 for R = 4.56° C.: and 1.296 against 1.30 for R = 5.61. This is a surprisingly close agreement.

VOLUME OF PHYTOPLANKTON AND THE DIATOM COUNT

Throughout this investigation it has been implied that variation in the measured volume of phytoplankton was primarily consequent upon similar variation in number of individuals of the prevailing species collected. The question naturally arises as to the extent to which this is true. In other words, what constituents of the phytoplankton are primarily responsible for the relation to upwelling water?

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This is not an easy question to answer, for the errors inherent in volumetric measurements are large and, in part, due to different causes from those inherent in counting the individual cells. On first thought it would seem as though the measured volume were due merely to those species, like *Chaetoceros criophilum*, that do not pack well upon settling: that the greater the number of individuals of such species the greater the measured volume. This, however, is only partly true. For example, of the thirty-six collections made during June 1918, the species were identified and counted in eighteen, and the coefficients of correlation between the measured volume and number of cells of the seven most prevalent species are given in the following list:[4]

Chaetóceros		
convolutum	+0.248	±0.133
decipiens	+0.367	±0.118
criophilum	+0.464	0.103
Nitschia		
seriata	+0.560	±0.087
pungens	+0.715	0.059
Thalassiothrix		
acuta	+0.803	0.042
frauenfeldii	+0.711	0.060
total diatoms	+0.842	0.034
total dinoflagellates	+0.151	±0.145

This list demonstrates several things: First, there is no apparent correlation between total dinoflagellates and volume, and the same fact seems to hold for each species, although the respective coefficients have not been computed. Second, the measured volume is not due merely, nor even primarily, to *Chaetoceros criophilum* and similar species that do not pack well: for, if so, how explain the fact that the coefficient of correlation is larger for *Nitschia seriata*, *N. pungens*, *Thalassiothrix acuta*, and *T. frauenfeldii* all of which pack far better than does *C. criophilum?* Third, and most important, the coefficient pertaining to the total diatoms is larger and more significant than that pertaining to any of the constituent species. This seems to indicate that all species behave with respect to upwelling water in essentially the same way and that the errors involved in catching and counting them tend to cancel in the total; or, it may be, that, as suggested by Herdman, Scott and Lewis (1913.

[4] In computing the coefficients of correlation the logarithms of the volumes and counts were taken. The reason for doing so is obvious: the logarithms are distributed in accordance with the Gaussian law of error; the quantities themselves are not.

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p. 28), at times and places favorable to the growth and reproduction of diatoms in general, "it takes very little to give some slight advantage to one of the numerous competing forms, so that it is enabled to forge ahead and for a short time, at least, far outnumber all the rest."

With respect to the sixteen collections made during July 1917, however, the relation between the measured volume and the counts is quite different. Reference to Table VII shows clearly enough that the relation between volume and upwelling water holds with essentially the same degree of precision as during June 1918. Yet the coefficient of correlation between the total diatoms and volume is insignificant ($+0.108 \pm 0.158$) although the species were identified and counted in each of the sixteen collections. Evidently this is due to error of some kind, and, since the greatest discrepancies have been verified by repeated counting, the error must be a manipulative one involved in making the collections. This is best recognized by comparison of hauls F42 and F93, the volume of the former being the greatest of all sixteen collections, whereas the latter contains the greatest number of diatom cells. The figures are:

Haul	Volume	Cells
F42	84 cc.	2,733,200
F93	48 cc.	48,504,800

The same inconsistency holds with respect to haul F52, containing the smallest number of diatom cells of the sixteen collections, and haul F84, containing the smallest volume. The figures are:

Haul	Volume	Cells
F52	15 cc.	194,950
F84	8 cc.	6,219,400

Consulting the original "field" notes in search of an explanation, it is found that the phytoplankton nets were new at the outset of the July 1917 trip, while they had been much used prior to the June 1918 trip. It is well known that such nets need to be "broken in"; that they catch best only after having become well "clogged" through repeated use. The reason is that nearly all species of phytoplankton are smaller, or only slightly larger than the mesh of the net. Bearing this in mind, Table I shows that, of the four hauls listed above, F42 and F52 were made on July 15th, and F84 and F93 on July 16th, F93 in

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fact being the last haul of the trip. This, I believe, explains why F93 obtained a greater number of cells than F42, even though the latter haul was made when reduction in temperature (see Table I) was greatest; and similarity with respect to hauls F84 and F52.

But how reconcile this with the opposite variation in volume? Evidently, the age of the net, though explaining the larger counts in the later hauls, has had little effect upon the measured volume. The only reason I can conceive is that the measured volume has been due mainly to those species whose cells were sufficiently large to be captured as readily in a new as in an old net, and that they were likewise of such a nature as to pack poorly upon settling thereby permitting the small cells to fill the interstices without materially altering the apparent volume. Obviously, *Chaetoceros criophilum* meets these requirements better than any other species. Accordingly, if this explanation be correct, the correlation coefficient between the measured volume and number of *Chaetoceros criophilum* captured during the July collections should be large. This proves true, the coefficient being $+0.985 \pm 0.004$. Further verification is had in the fact that *Chaetoceros decipiens* and *Nitschia seriata*, the smaller cells of which are readily lost through the meshes of a new net while the larger ones are not, give coefficients ($+0.272 \pm 0.138$ and $+0.207 \pm 0.147$ respectively) intermediate between that for *Chaetoceros criophilum* and that for the total diatoms.

The relation of diatom count to measured volume during the remaining months, though complex, seems to fall between that found for July 1917 and June 1918. But, because the relation between volume and upwelling water is not so precise, this is uncertain. Summarizing the relations during June and July, two conclusions of general significance are suggested: First, when collections are made under comparable manipulative conditions, as was most nearly realized in June 1918, variations in volume of phytoplankton, measured by the settling method, are approximately proportional to variations in the number of diatom cells taken as a unit irrespective of kind. Second, when the age of the net enters as an important factor in collecting, the volume, measured by the settling method, represents more accurately than the counts, excepting, perhaps, those of *Chaetoceros criophilum* and similar species, the actual variation in the distribution of diatoms from place to place.

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SUMMARY AND CONCLUSIONS

The most important facts revealed by this investigation are summarized as follows:

1. Between July 1917 and June 1918 and within a strip of water extending approximately one hundred twenty-five nautical miles seaward from Point Fermin, volume of phytoplankton, collected in vertical hauls from 200 meters to the surface, when corrected for the effect of season, increased, on the average, from a minimum nearest shore to a maximum about seventy miles off, and then decreased with further increase in distance.

2. The surface temperature, simultaneously observed at the places phytoplankton was collected, decreased on the average, when corrected for the effect of season, from a maximum nearest shore to a minimum about seventy miles off, and then increased with further increase in distance.

3. The coefficient of correlation between temperature and volume of phytoplankton, each corrected for the effect of season, is —0.4596 ± 0.033, or, when each is also corrected to a constant distance, —0.2597 ± 0.042.

From these facts, together with what is known of the flow of water upwelling along the coast between Point Conception and Point Fermin, and off the Channel Islands, and its effect in reducing the surface temperature, it is concluded that an increase in amount of upwelled water leads to an increase in quantity of phytoplankton, a conclusion that is supported and amplified by the further facts:

4. During the summer months, July and August 1917, and May and June 1918—the season of maximum upwelling—the coefficient of correlation between volume of phytoplankton and temperature is —0.602 ± 0.036; while during the winter months, November 1917, and January, February, and March, 1918—the season of minimum upwelling—the coefficient is —0.215 ± 0.063.

5. During the summer months, volume of phytoplankton increased approximately in geometric progression as reduction in temperature below that normal for the latitude increased in arithmetic progression.

6. For an increase of one degree in temperature reduction between 0.5° C. and 6.3° C., volume of phytoplankton increased, on the average, between 1.3 and 1.4 times: this is true with respect to the data for July 1917, for June 1918, for August 1917 and May 1918 combined, and for the four months combined;

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and also in this last instance for ranges in temperature reduction of 0.5° C. — 3.2° C., 3.5° C. — 5.1° C., and 5.2° C. — 6.3° C., separately considered.

7. On the basis of eighty-eight observations, the reduction in temperature is computed from the volume of phytoplankton *collected by a single net haul* within a probable error of 1.5° C.

8. From an equation expressing the theoretical relation between rate of photosynthesis, hydrogen-ion concentration of the water, and temperature of the water, and an empirical one, based on observations made during July 1919, expressing the relation between hydrogen-ion concentration and temperature reduction, the form of equation relating volume of phytoplankton to the temperature reduction is deduced and found to agree with that ascertained empirically.

9. On the same basis it is deduced that the magnitude of the coefficient denoting the increase in volume of phytoplankton for an increase of one degree in temperature reduction (mentioned under 6), should vary inversely with the magnitude of the temperature reduction, and this proves true (Table V). Moreover, the magnitude of three coefficients are estimated from a fourth one within a maximum error of 1.5%.

These facts strongly suggest a law of relationship between amount of upwelling water and the organic fertility of the sea in an upwelling region. Many more data are needed, however, in order to test its general validity. Especially is the need apparent not only of further study of the distribution of phytoplankton during each month of the year, but of an intensive investigation of the horizontal and vertical distribution of the hydrogen-ion concentration of the water.

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SOLUTION OF EQUATIONS

In isolating the effect upon volume of phytoplankton of those influences associated with distance from the coast from those associated with season, the method of successive approximation, described by McEwen and Michael (1919, p. 100) for the case when variability within the group is neglected, is used. Designating by A, B, C, D, E, F, G, and H, the logarithmic means for July, August, November, January, February, March. May, and June, each corrected to a constant distance (46.7 miles from Pt. Fermin); and by I, J, K, L, M, and N, the logarithmic means for the first, second, third, fourth, fifth and sixth distance groups given in Table III, each corrected to May 1918, the following equations, similar to (7) to (15), in the above paper are derived:

$$A = 1.416+\frac{1}{16}(3i+j+2l+5m+3n) \qquad (18)$$

$$B = 0.671+\frac{1}{13}(7i+4j) \qquad (19)$$

$$C = 0.363+\frac{1}{26}(4i+4j+5l+6m+2n) \qquad (20)$$

$$D = 0.020+\frac{1}{31}(4i+3j+6l+6m+6n) \qquad (21)$$

$$E = 0.177+\frac{1}{13}(4i+4j+2l) \qquad (22)$$

$$F = 0.884+\frac{1}{16}(4i+4j+4l) \qquad (23)$$

$$G = 1.238+\frac{1}{23}(4i+4j+4l+6m) \qquad (24)$$

$$H = 0.945+\frac{1}{36}(4i+2j+8l+6m+12n) \qquad (25)$$

$$I = 0.534+\frac{1}{34}(3a+7b+4c+4d+4e+4f+4h) \qquad (26)$$

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$$J = 0.539 + \frac{1}{26}(a + 4b + 4c + 3d + 3e + 4f + 2h) \tag{27}$$

$$K = 0.726 + \frac{1}{31}(2a + 2b + 5c + 6d + 3e + 4f + 4h) \tag{28}$$

$$L = 0.860 + \frac{1}{31}(2a + 5c + 6d + 2e + 4f + 8h) \tag{29}$$

$$M = 0.746 + \frac{1}{29}(5a + 6c + 6d + 6h) \tag{30}$$

$$N = 0.702 + \frac{1}{23}(3a + 2c + 6d + 12h) \tag{31}$$

where $i = K - I$, $j = K - J$, $l = K - L$, etc. as defined by McEwen and Michael (1919, p. 103).

Solution of these equations gives

$A = 1.503$, $B = 0.868$, $C = 0.435$, $D = 0.040$, $E = 0.300$, $F = 0.960$, $G = 1.321$, $H = 0.995$, $I = 1.067$, $J = 1.122$, $K = 1.321$, $L = 1.436$, $M = 1.231$, and $N = 1.258$; which are correct to one in the third decimal. The antilogarithms of A to H are the geometric means for the respective months corrected to a constant distance from the coast, and those of I to M are the geometric means for the respective distance groups corrected for the effect of season (see Table IV).

In making the correction for temperature the same equations (18 to 31) are used except that A, B, C, etc., designate the corrected temperature averages instead of the corrected logarithmic means of the volumes, and that the original logarithmic means (1.416, 0.671, etc.) are replaced by the original temperature averages. The equations so altered together with the final values, correct to 0.01° C, are

$$A = 17.28 + \frac{1}{16}(3i + j + 2l + 5m + 3n) = 17.19^\circ \text{C.} \tag{32}$$

$$B = 19.05 + \frac{1}{13}(7i + 4j) = 17.76^\circ \text{C.} \tag{33}$$

$$C = 17.21 + \frac{1}{26}(4i + 4j + 5l + 6m + 2n) = 17.03^\circ \text{C.} \tag{34}$$

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$$D = 15.17+\frac{1}{31}(4i+3j+6l+6m+6n) = 15.12°C. \quad (35)$$

$$E = 13.92+\frac{1}{13}(4i+4j+2l) = 13.10°C. \quad (36)$$

$$F = 14.46+\frac{1}{16}(4i+4j+4l) = 13.92°C. \quad (37)$$

$$G = 14.88+\frac{1}{23}(4i+4j+4l+6m) = 14.63°C. \quad (38)$$

$$H = 16.94+\frac{1}{36}(4i+2j+8l+6m+12n) = 17.02°C. \quad (39)$$

$$I = 17.44+\frac{1}{34}(3a+7b+4c+4d+4e+4f+4h) = 16.21°C. \quad (40)$$

$$J = 16.91+\frac{1}{26}(a+4b+4c+3d+4e+4f+2h) = 16.06°C. \quad (41)$$

$$K = 15.55+\frac{1}{31}(2a+2b+5c+6d+3e+4f+4h) = 14.64°C. \quad (42)$$

$$L = 14.93+\frac{1}{31}(2a+5c+6d+2e+4f+8h) = 13.85°C. \quad (43)$$

$$M = 15.67+\frac{1}{29}(5a+6c+6d+6h) = 14.14°C. \quad (44)$$

$$N = 16.30+\frac{1}{23}(3a+2c+6d+12h) = 14.39°C. \quad (45)$$

In applying the slope method to determine the form of equation relating volume of phytoplankton to reduction in temperature the process followed is precisely the same as that described by McEwen and Michael (1919) on page 111, and illustrated on page 125. Designating by A, B, C, and D, the logarithmic means for the months of July and August 1917, and May and June 1918, by E, F, and G the logarithmic means for the three temperature reduction groups, and by $\bar{S}_E$, $\bar{S}_F$, and $\bar{S}_G$ the slopes pertaining to each of the three reduction groups, equations anal-

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ogous to (118) to (123) of McEwen and Michael's (1919) paper are derived. These equations are:

$$A=1.4161+0.1250e+0.5625g-[S_E(-0.0806)+S_F(-0.0191)+S_G(+0.03075)] \quad (46)$$

$$B=0.6711+0.5385e+0.1538g-[S_E(+0.03762)+S_F(-0.0957)+S_G(-0.0326)] \quad (47)$$

$$C=1.2380+0.4348e+0.4348g-[S_E(-0.0278)+S_F(-0.0427)+S_G(+0.0730)] \quad (48)$$

$$D=0.9452+0.2222e+0.3333g-[S_E(-0.0819)+S_F(+0.0701)+S_G(-0.0484)] \quad (49)$$

$$E=0.7771+0.0741a+0.2593b+0.2963d \quad (50)$$

$$F=1.0632+0.1786a+0.1429b+0.5714d \quad (51)$$

$$G=1.3068+0.2727a+0.0606b+0.3636d \quad (52)$$

where $e=F-E$, $g=F-G$, $a=C-A$, $b=C-B$, and $d=C-D$.

But S_E, S_F, and S_G may be expressed in terms of e and g. That is

$$S_E=0.6780e+0.6720g \quad (53)$$

$$S_F=0.1170e-0.6720g \quad (54)$$

$$S_G=-0.1170e-1.2328g \quad (55)$$

whence equations (46) to (49) reduce to

$$A=1.4161+0.1855e+0.6418g \quad (56)$$

$$B=0.6711+0.2908e-0.2035g \quad (57)$$

$$C=1.2380+0.4672e+0.5148g \quad (58)$$

$$D=0.9452+0.2638e+0.3757g \quad (59)$$

Solution of equations (50) to (59) gives the following values, correct to the third decimal: $A=1.395$, $B=0.786$, $C=1.319$, $D=0.981$, $E=1.010$, $F=1.319$, $G=1.441$, $S_E=0.1275$, $S_F=0.1181$, and $S_G=0.1142$. The antilogarithms of E, F, and G are the corrected volumes, and those of S_E, S_F and S_G are the common ratios given in Table V. The value of S in equations (5) and (6) is equivalent to $C-A=a=-0.076$ for July 1917, $C-B=b=0.533$ for August 1917, and $C-D=d=0.338$ for June 1918.

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MISCELLANEOUS PAPERS ON OCEANOGRAPHY

THE SCIENCE OF OCEANOGRAPHY

By George F. McEwen

INTRODUCTION

Owing to the comparatively recent development of the science of oceanography, and to the more or less vague and conflicting ideas as to its nature and scope, it seems desirable to attempt to define and explain briefly this extensive field. Also, in keeping with the series of papers to follow, attention will be called especially to the physical oceanography of ocean water masses.

The word "ocean" denotes the great connected sheet of water, which covers most of the earth's surface. Oceanography is the science which would deal exhaustively with the ocean, and is, therefore a large and important part of the essentially synthetic science of geography, whose subject matter is, for convenience, divided into the three geospheres, the atmosphere, the lithosphere (hard rocky crust of the earth), and finally the hydrospheres, which include all of the water, both on the earth's surface and in the atmosphere. The ocean is accordingly less than the hydrosphere.

The term Thalassography, originally used by the Ancient Greeks to denote the description of the Mediterranean, came to be applied to all oceanic investigations. However, in 1880, before usage of the old word, with this widened meaning, became established, the more appropriate term, oceanography, was introduced by Sir John Murray, and has since come to be the generally accepted name for the science of the sea. The limiting expression, physical oceanography, is used when the life of the ocean is excluded from consideration, the expression, biological oceanography denotes the science of the life of the sea, while the unmodified term, oceanography, includes both of the above expressions.

The term hydrography, although having some currency as a substitute for physical oceanography, includes much that is not comprehended by the latter expression, and ought to be reserved for certain engineering operations, especially those pertaining to

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rivers and harbours, and to nautical surveying, carried on for the purpose of making charts and tables to be used in navigation.

Finally, as in the science of geography, two types, general and special oceanography are distinguished, according to the method of investigation, or object in view. General oceanography deals with phenomena common to the ocean as a whole, while special oceanography deals with individual characteristics of any portion of any one of the oceans.

DIVISIONS OF OCEANOGRAPHY

The science of oceanography will now be more fully defined. In the organic world, the most distinctive phenomena follow from stimuli, wills and motives, thus giving rise to an extraordinary complexity of the relations, and involving properties different or in addition to those of lifeless matter and energy, with which the physicist and chemist deal. For this reason a complete physical explanation of organic phenomena is, to say the least, a long way in the future, and it is admitted that, for the time being, the immediate connections can not be discerned. Organic phenomena can at present be only remotely comprehended from the standpoint of physical causation, and their explanation and interpretation must invoke the ideas of adaptation and purpose. On the other hand, investigations of earth phenomena, exclusive of life, are relatively more simple and more amenable to fundamental causal treatment from the standpoint of physics and chemistry. It is thus natural, and convenient to deal separately with the animate and inanimate worlds, as illustrated by such divisions of science as botany, zoölogy, and anthropology, on the one hand, and geology, geophysics and astronomy on the other. However, from certain points of view, the ecological one, for example, interrelations between the two provinces are considered, and such investigations of the animate world are necessarily dependent upon results of certain investigations in the inanimate world. Moreover, the methods of dealing with the latter have a strong influence on methods in biology.

Biological oceanography,[1] or the equivalent expression, marine biology, is the science which aims to deal exhaustively with

[1] Special attention is given to the biological part of oceanography in the following paper:
"Oceanography and the Sea-Fisheries," Presidential address delivered at the Cardiff meeting of the British Association on August 24, 1920, by William A. Herdman, Professor of Oceanography in the University of Liverpool, Nature, Vol. 105, No. 2652, pages 813-825. August 26, 1920.

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life as it manifests itself in the sea. It involves more than a list of the species of all the animals and plants of the sea, together with a description of each. That is, marine biology is not merely morphological and taxonomic. Life histories, phenomena of reproduction, feeding habits, migrations, associations, abundance, and relations to environmental factors are fundamental in this science. The field method of investigation, in which control over conditions is much limited, or practically impossible, is dominant in biological oceanography. Marine biology as illustrated by biological investigations most cultivated at the Scripps Institution, especially during the last fifteen years, is thus distinguished from general biology, even though marine organisms be used as material for the experiments. For example, a good deal of laboratory work has been done on marine organisms in connection with some special biological inquiry, such as phenomena of the nervous system, reproduction or reactions to stimuli. But this is not biological oceanography, although results of such experiments may be of value in interpreting field data. Accordingly certain results of physical oceanography are necessary in truly marine biological investigations. In fact, physical oceanography owes much of its progress to the needs of marine biology.

The science of physical oceanography may, for convenience be divided into three subdivisions. Under the first head are included topographical features, the depth, the magnitude and volume of the ocean basins, the cross-section areas at different depths, and the form of the bottom, or submarine relief. The incentive to much of the pioneer work in submarine relief was the necessity of obtaining an accurate knowledge of bottom topography, in order to lay ocean telegraph cables. And the possibility of attaining the requisite accuracy (a depth error less than 5 fathoms) in deep-sea sounding is due to the invention, in 1854, of a sounding device in which the weight is detached when striking the bottom.

The second division deals with the nature of the bottom, the bottom sediments, their amount, kind, distribution, physical and chemical properties, and origin or source. There is a close inter-relation between this second subdivision and certain aspects of marine biology, since the sediments are made up, in part of enormous quantities of the remains of marine organisms.

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The third and last subdivision deals with the physical and chemical properties of sea-water, and with the physics and chemistry of the water masses in the ocean, that is, with physical and chemical phenomena as they take place on a large scale in nature. The development of this third division, especially with respect to surface phenomena, is due, in a great measure, to the needs of navigation, and the interest and coöperation of navigators.

While all of these special provinces of physical oceanography are independent in certain dominant features, they are more or less related in other respects. As the investigation of any one proceeds to exhaustiveness, the data and conclusions of the others must be increasingly drawn upon. Both in making observations, and in interpreting and coördinating them, it is necessary to call in the aid of various other sciences, astronomy, geology, meteorology, physics, and chemistry. Thus, physical oceanography is essentially a synthetic science, and as applied to ocean waters includes, first, the accurate measurement, throughout the ocean, of the physical and chemical properties of the water, such as its temperature, motion, salinity, gas content, and acidity, and second, the precise formulation of problems suggested by these data and the corresponding meteorological and astronomical data, with a view to coördinating and interpreting the direct objective knowledge, and thereby discovering general laws of the phenomena of the sea. However, geophysics, of which physical oceanography is a part, is not a mere hotch-potch of certain portions of physics, chemistry, mathematics, etc. The object of geophysics is to determine from the standpoint of these sciences the basic phenomena of the earth throughout its whole extent, regarded as an organic whole, whose processes take place in accordance with general laws.

OCEANOGRAPHY, AS APPLIED TO OCEAN WATER

Investigations relative to the ocean waters fall into three distinct classes: laboratory experiments conducted on samples of sea-water for the purpose of determining their physical and chemical properties; observations and collections made at sea for the purpose of obtaining a description of the physical and chemical conditions of the ocean; and finally theoretical studies based on such objective knowledge, and made with a view to

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coördinating and interpreting oceanic phenomena. These three classes will now be considered in the order mentioned.

Laboratory experiments made on numerous samples of sea water have demonstrated that the water of the ocean is a mixture of dilute solutions of various salts, whose proportions remain nearly constant, even though the absolute mass of salts per kilogram of water (called the salinity) varies considerably. Detailed and carefully conducted measurements of the various physical and chemical properties of sea water, resulting in a list of constants, tables and formulae giving the numerical relation between different properties, while essential, both for observational and theoretical oceanic investigations, are but aids to the main purpose of obtaining a knowledge of the ocean.

Among the physical properties and interrelations that are of most importance, and that have been most carefully worked out are: first, the relation of specific gravity to temperatures, salinity and pressure; second, specific heat, freezing point, boiling point ,and third, vapour pressure, surface tension, viscosity, heat and electrical conductivity, transmission of solar radiation, refractive index, and their relation to salinity, and temperature.

Among the important chemical investigations of samples of sea-water are: determination of the elements and their amounts, composition of oceanic salts and their proportions, the salinity or absolute mass of dissolved solids per kilogram of sea-water, the relation of salinity and temperature to osmotic pressure, and the solubility of various gases, especially nitrogen, oxygen, and carbon dioxide.

In addition to describing sea-water and its behavior as a *substance*, by means of physical and chemical constants, and quantitative relations between its various properties, physicists and chemists have made important advances in devising practicable methods of making observations, both in the field and on samples collected for the purpose of obtaining the distribution, in the sea, of temperature, salinity, gas content, acidity, etc. The interrelations between various properties, such as specific gravity to temperature and salinity, electrical conductivity to salinity and temperature, and the acidity to hydrogen ion concentration have been of fundamental importance in this connection. Also various mechanical appliances devised for measuring depths, currents, tides, and waves, and for collecting samples have contributed greatly to the precision of field work.

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With the exception of the phenomena of motion which are considered later, the most important things that are attempted in making field observations relative to the water are: determination of the distribution throughout the ocean of temperature, salinity, gas content, and acidity. Compilations of a sufficient number of such observations properly distributed in space and time indicate the relation of such magnitude to latitude, distance from the coast, and depth. Also, seasonal and diurnal changes, both horizontal and vertical gradients, and normal or mean conditions about which the values fluctuate, are thus determined.

The phenomena of motion constitute a large and important branch of physical oceanography and may be considered under four heads: tides, waves, the general oceanic circulation, and the alternating motion of small water masses, due in part to variations in density and resulting in a mixture of water masses of different properties.

The tides, owing in part to their great and early recognized importance in navigation, and in part to the great interest of the corresponding cosmical problems in theoretical mechanics, have been extensively investigated. Continuous measurements of the height of the tide accompanied by wind observations are made at a number of carefully selected stations throughout the civilized world, as a part of the work of hydrographic and coast survey departments of various governments. These continuous measurements and observations are supplemented by numerous fragmentary data from many other places. Also a beginning has been made toward the regular measurement of corresponding currents, for the purpose of obtaining the relation of tidal currents to heights of the tide.

Although waves are, in general, the most familiar and obvious of the phenomena of oceanic motion, they have received neither as extensive nor, as a rule, as careful atteniton as have tides. Many reports pertaining to dimensions of waves are based on mere guesswork, and there is a considerable diversity of opinion as to their size. However, numerous trustworthy observations with the unaided eye have been made by certain individuals, and greater precision has, in late years, resulted from the use of various instrumental aids. At sea, attention is directed mainly to height, length, velocity, and period; near shore additional observations are made on their change of form as the depth decreases, and on their transporting and abrading

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power. Measurements of the impact of waves on a vertical plane have also been made as an aid to engineers in designing certain structures.

In addition to these visible waves, modern investigations have revealed the presence of "internal" or "boundary" waves which are formed at times when a relatively light layer of water is sharply separated from denser water underneath. Although such waves, formed at the boundary of two water layers have much greater dimensions than at the surface, they disturb the surface but little if any.

Although the flow of water in ocean currents is rarely so evident to the eye of the casual observer, as are tide or wave motion, this phenomenon of general circulation is just as characteristic, and according to the accumulated evidence, takes place on a vast scale comparable in magnitude to the ocean itself. Observations without instrumental aid can in general reveal but little information concerning ocean surface currents, and nothing about subsurface currents. Direct observations of currents with the aid of floats or current meters require conditions rarely met with on the high seas. For observations, even on surface currents, we are largely dependent on indirect means, for example, such mechanical ones as drift bottles or drifters set adrift at known positions, and times, and the departure of ships from their apparent courses. Current observations are, in general, far from being as precise as observations of other physical phenomena of the ocean water, and the most accurate current observations have been made in shallow inshore waters, or in rare instances from especially equipped ships at anchor in deeper waters. From the standpoint of field observations, there is doubtless no branch of physical oceanography in greater need of improvement than that dealing with circulation.

However precise and complete oceanic observations may be, merely making and compiling them is but the first step in the investigation of the ocean. The full return from such efforts can come only from attempting to coördinate and interpret the objective knowledge. This object demands the definite formulation and solution of numerous and varied special problems suggested by the ocean and other cosmical data with a view to discovering causal relationships between the various phenomena and showing their harmony with general principles already established by investigations in other fields. By thus obtaining

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a series of definite and proved relations, each relation involving two or more types of physical or chemical magnitudes, and by a synthesis of these elementary results we approach the ideal of a system of general laws of the sea based on objective knowledge, and adequate for describing the many diverse phenomena in terms of relatively few and simple fundamental ones. Also laboratory experiments with the aid of small bodies of water have contributed toward an understanding of various ocean phenomena. For example, by cooling certain portions of a tank of water and warming other portions, a definite type of convective circulation is set up, and the whole phenomena of temperature distribution and flow can be observed in detail. With additional equipment the effect on the circulation of obstructions or air currents can also be observed. Again, in certain instances, small models of lakes, seas, and harbours have been constructed in order to study the particular tidal oscillations or seiches occurring in the larger bodies of water. In these cases the principle of "dynamic similarity" must be used in an accurate quantitative comparison of the models with the corresponding larger bodies.

Owing to various practical difficulties of making direct observations, current measurements for example, even the first task of determining physical and chemical magnitudes pertaining to the ocean becomes more feasible, and can be more accurately and completely executed, with the aid of causal relationships between the phenomena, than is possible if only direct determinations are attempted. Thus the objective and theoretical aspects of oceanic investigations are mutually dependent; available observations render possible sound theoretical developments which, in turn, serve indirectly to increase our knowledge even of processes not admitting of satisfactory direct observation.

In order to explain more fully the field of physical oceanography as applied to ocean waters, and to illustrate some of the general statements pertaining to its theoretical side, attention will now be called to a number of special problems and questions.

First among the questions that arise in connection with the subject of waves, are the following: What height of waves will a wind of given velocity produce? With what velocities do waves travel, and how are the velocities related to the corresponding determining factors? How do the individual water particles of a wave move? What is the relation of period to wave-length? With the exception of the first question, answers

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have been deduced by applying principles of mechanics to the appropriate data, and in general the agreement between computed and observed values has been reasonably good. In fact, one of the most successful applications of hydrodynamics is to small oscillations under gravity of a liquid having a free surface. The first question involves corresponding measurements of waves and wind, which, together, afford a basis for obtaining empirical relations, but, while some progress has been made in the theoretical side of this question, the results attained are not as satisfactory as in the case of the other questions just asked.

Great progress has been made in investigations of the tides, and wave theories play an important part in them. With the aid of relevant data which must include observations of the height and time of the tide at a given place, combined with principles of physical astronomy, it is possible to make satisfactory predictions of the time and height of the tide at that place a year or more in advance. But, mathematicians have not yet succeeded in deducing the tides entirely from principles of mechanics and the elements admittedly determining them, such as the topography of the ocean bottom, the distribution of land and water and the relevant astronomical data. Thus, while existing methods, partly empirical and partly theoretical, are adequate for most practical purposes of navigation, the science of the tides, considered as a physical phenomenon, is still in a preliminary stage on the way to a solution of tidal problems approaching in completeness the solution of other problems in physical astronomy.

Determination of the general oceanic circulation, and its variations is especially difficult, and this field of investigation not only shows clearly the need of indirect methods, but affords a striking illustration of the way in which the observational and theoretical aspects combine in attaining the desired end. Investigations of ocean currents may be approached from the dynamical side in which case, the currents are regarded as the effect of a set of causes or they may be regarded as causes producing certain effects. The first or dynamical method requires investigations of the causes of currents, and these causes may conveniently be divided into two classes: primary, such as winds, variations in air pressure, differences in specific gravity; and secondary, such as coastal and bottom configuration, the earth's rotation and fluid friction. But, the theoretical determination of

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currents from their causes, even though the latter may be known, is in general, extremely difficult. While a good deal has been accomplished in this direction, especially considering the few men who have given special attention to the matter, the subject of the dynamics of ocean currents is far from satisfactory.

The important phenomenon of friction in the sea, where turbulence and the alternating circulation of small masses of water prevail, is entirely different from viscosity, as measured in the laboratory experiments, in which the attempt is made to produce a slow laminar motion and to determine the frictional properties of the *substance* water. Lack of appreciation of this fundamental difference has rendered the results of earlier mathematical investigations involving friction in the sea entirely misleading from a quantitative point of view.[2] But the need is being recognized of giving more careful attention to the subject of frictional resistance in the sea, not only in the case of general oceanic circulation, but in tidal investigations as well.

The circulation may be regarded as one of the dominant and variable factors, or causes tending to disturb the distribution of temperature, salinity, and other properties of sea-water. Accordingly, inferences regarding the circulation may be based on modifications of the normal distribution of properties of the water. This method which has long been used in a qualitative way, demands, for quantitative treatment, investigations of the distribution of these properties, temperature, for example, as consequences of factors other than ocean currents. Accordingly it is necessary to investigate the phenomena of heating of the water due to solar radiation, cooling due to evaporation, conduction of heat under oceanic conditions, the corresponding changes in salinity and other properties, the direct effect of contact with air, and the modifying influences on such phenomena of depth and distance from land. The fundamental problem of vertical temperature gradients and their relation to physical causes has received but little attention except from the qualitative point of view. The theoretical treatment of this problem, using the principle of statistical mechanics, and the idea of a convective or alternating motion of small water

[2] Geo. F. McEwen, Physical constants pertaining to the ocean, Science, N. S. Vol. LII, No. 1333, pages 62-63, June 16, 1920. Oceanic circulation and its bearing upon attempts to make seasonal weather forecasts. Bulletin No. 7 of the Scripps Institution for Biological Research of the University of California, pages 1-26, November 8, 1918.

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masses, tending to mix the water, has been attempted by the writer, and preliminary results thus far reached are encouraging. Moreover, it appears that this mixing phenomenon is closely related to that of friction, as well as to the general phenomenon of diffusion and heat conduction in the sea. From the standpoint of coördinating and interpreting results the importance of such relations is evident.

Finally, smaller bodies of water—lakes and reservoirs—may be regarded as models whose intensive investigation should aid greatly in attacking the more complex problems of gradients in the immense ocean masses for which available data are correspondingly incomplete, and difficult to obtain.

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INVESTIGATIONS OF THE WATERS OF THE PACIFIC

By George F. McEwen

THE PACIFIC AS A WHOLE

In certain previous papers the author has dealt, in a general way, with the science of physical oceanography, agencies available for making observations, and ideas regarding organization, coöperation and individual work. The present paper deals more specifically with investigations of the Pacific ocean, and naturally pertains mainly to local (North American) waters.

The circulation of the waters in the Pacific basin is known only in a very general way, and most of the data on which this knowledge is based were obtained by men having but little training in this field, and neither provided with special apparatus, nor afforded time for its use. Such accompanying observations of ocean temperatures as have been made from commercial ships relate only to the surface. Even the oceanographic observations made by the various scientific expeditions relate mainly to the surface and bottom. The intermediate depths have received but little attention. In fact, prior to the year 1909 serial temperature observations that can be regarded as reasonably trustworthy had been made at scarcely 700 stations in the whole Pacific, that is, on the average, there was available only one vertical series for each 50,000 square miles. And only a small proportion of these temperature observations were accompanied by serial water samples collected for physical or chemical examination. Moreover, the depth interval between observations even in the upper changeable layer 200 to 300 fathoms in thickness was rarely less than 50 fathoms. Again these subsurface observations, accumulated during a forty year period, with no continuity in the time sense, were irregularly scattered over the ocean with little regard to critical regions, and lacked the homogeneity insured by the use of standard methods.

The subsurface work done since 1909 relates to only a few very limited regions, for example small areas off the coasts of Japan, certain Pacific islands, and the continent of North America. Only a little preliminary work has been done on the chemistry of the Pacific Ocean. This important, but practically untouched field is dealt with in other papers of the proceedings.

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however, certain outstanding features are briefly mentioned here. It is commonly assumed that the ocean waters are everywhere of the same chemical composition, or that the proportions of the various salts remain constant even though there may be wide variations in absolute amounts. However, there is a reciprocal action between the substances dissolved in the ocean and those of its floor, the river water flowing in, and the marine life. The slight changes in composition of the ocean waters thus arising, form an important and neglected field of research at least in the Pacific. The systematic measurement of acidity, alkalinity, and the amounts of dissolved gases, especially oxygen, nitrogen, and carbon dioxide must also be included in any thorough-going program of ocean research.

Such discontinuous and fragmentary observations thinly scattered over the whole ocean can provide scarcely more than a crude idea of the general or prevailing aspects of circulation and the distribution of temperature, salinity or other properties. The details of their distribution and seasonal variations are unknown. And the more intensive and continuous local work of the kind hitherto carried on by individuals or institutions in very limited regions can never compass the great ocean as a whole. The Pacific is vast, and contains an infinite variety of conditions and phenomena. Thorough-going Pacific investigation therefore demands munificent support and international coöperation. Plans involving practicable series of observations continuous in the time sense as well as in space, and extending over long periods should be thoughtfully worked out in advance. Careful preparation for each scientific expedition is essential, and the prearranged program should be followed closely, although it is important to provide for such additional work as may seem advisable during the progress of the work. The details of such a program can not be properly worked out by scientists alone, navigators should also be called in conference in order to insure practicability of plans and economy of expenditure.

Determination of the diurnal and seasonal changes of temperature, salinity and other properties at sufficiently small depth intervals in selected positions is greatly needed. Also observations subject as little as possible to the perturbing influence of land, currents and winds are especially desirable for the purpose of investigating "normal" vertical gradients and their seasonal variation. The question of vertical gradients in the ocean is of

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fundamental importance in the science of oceanography. It involves the idea of the alternating circulation of small water particles, which according to the indication of present researches cause conduction and diffusion under conditions peculiar to large bodies of water. Again, this phenomenon is closely related to the important but little known subject of fluid friction or resistance to motion in the sea.

One region where observations would be well adapted to the needs of such investigations is a sort of "oceanic lake" under the area of high barometric pressure in the North Pacific, and included between latitudes 30° to 55° N. and longitudes 130° to 180° W. There is a similar one in the South Pacific included between latitudes 15° to 42° S. and longitudes 75° to 130° W. Oceanographic observations in such regions accompanied by meteorological observations such as cloudiness, solar radiation, air temperature, humidity, barometric pressure and wind would provide a satisfactory basis for working out the principles of vertical gradients of physical and chemical properties of sea-water resulting from the simplest conditions. A study of such data would reveal the way in which land masses, winds and ocean currents influence the distribution of these properties. In connection with such a program relative to one or both of the high pressure areas there should also be one of continuous observations at selected stations along coasts and in the equatorial region, of as many properties of the water as possible, especially the temperature, salinity, gas content, hydrogen ion concentration, and currents accompanied by meteorological observations. Thus a variety of diverse but related phenomena could be coördinated.

THE WATERS BORDERING NORTH AMERICA

First in importance would be serial temperatures and salinities along a number of cross-sections extending from the coast out through the Japan Current. Regions in which such observations would be of special interest are the following, extending south from latitude 50 N. to 20 N.: Vancouver, Astoria, Cape Blanco, Cape Mendocino, San Francisco, Point Conception, Point San Eugenio, Magdalena Bay, Cape San Lucas, and Cape Corrientes. Supplementary observations of the winds, surface drift, barometric pressure and certain chemical properties of the water would greatly increase the value of the other observations. Also similar observations should be made along two lines, one approx-

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imately parallel to the edge of the continental shelf, the other in a southwesterly direction near the middle of the Japan Current, that is, about 300 miles off shore from Vancouver and 1500 to 2000 miles off shore from Cape Corrientes. The results of observations along the various cross-sections would serve to determine the best location for these two lines, and might indicate the need of others also.

When deciding on the details of such a program according to available means, it would seem best in the interest of continuity, so to reduce the area traversed as to make observations possible at time intervals not exceeding two months. Such an investigation, even if the cruises could be carried on for only a year, would add much to our knowledge of the details of the upwelling phenomena as well as the cold California Current, its extent and relation to the Japan Current. It would furnish an approximation to the seasonal variation of the different elements observed. Moreover, such data would contribute to the solution of the following general oceanographic and meteorolgical problems.

1. The relation of winds to changes in water level, and the current generated by a wind of given velocity.

2. The relation of barometric pressure to winds, currents and water level.

3. Differences in water level as a cause of ocean currents.

4. The detection and measurement of ocean currents by means of the variation and distribution of one or more chemical or physical properties of the water.

5. The effect of the bottom configuration and coast line on circulation.

6. The motion produced by a neighboring current.

7. Erosion and deposition by ocean currents.

8. The precipitation of various substances due to varying physical and chemical conditions of the water.

9. "Boundary waves", that is waves in a body of water covered by a layer of less density, sharply separated from the underlying denser water.

10. The relation of land climates and weather to ocean conditions, and the possibilities of seasonal weather forecasting from ocean conditions.

In conclusion the value of certain oceanographic observations as a means of long period weather forecasting has been

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indicated by continuous records for the past six years at the Scripps Institution pier, near San Diego. A continuous, and more extended series of observations for a period of many years will be required to test the possibilities of such forecasting methods. For this purpose, advantage should be taken of the adaptability of government light ships, light houses, and other stations near shore, to such a continuous series of observations.

ACCURACY AND DISTRIBUTION OF OBSERVATIONS

More attention than has been customary should be given to the upper 200 meter layer of water. From temperature and salinity observations it appears that, in general, a suitable distribution of observations in this layer is: 0-5-10-15-20-25-30-40-50-60-75-100-125-150-200 meters. Below 200 meters a 100 or 200 meter interval is in general small enough except in special investigations of the possible warming effect near the bottom due to the earth's heat.

The proper distance between stations at which serial observations should be made varies widely with conditions. In certain in-shore regions where the depth changes rapidly, intervals as small as 0.2 mile are often desirable, while 10 or 15 miles off shore a 5 mile interval may suffice, still farther off shore conditions are often so uniform that a much longer interval, say 30 miles, may suffice. It is desirable to carry on regular surface collecting at small equal intervals say every 2 miles, while under way, and to be guided by these results, as well as by topographic features in the selection of stations for serial observations.

Temperatures measured to 0.1 C are accurate enough for many purposes, but it is in general desirable to estimate to 0.01 C., especially in making serial observations. The salinity (number of grams of salts per 1000 grams of solution) should in general be measured with an error not exceeding 0.02 grams which is about 0.1% of its usual value. This corresponds to an error of about .002% or 1 part in 50,000 in specific gravity. Such precision is practicable when using methods already perfected. (See paper by N. W. Cummings, in this volume.)

In general a depth error not exceeding about 0.5 meter down to 25 meters, and not more than 2% of the depth from 50 meters to the bottom will prove to be satisfactory and practicable.

Locations of positions should be as accurate as conditions permit. When close to land position errors can often be kept

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within 0.10 mile, while an error less than 1 or 2 miles can hardly be expected when out of sight of land. Modern radio methods of location at sea promise to be of great value both commercially and scientifically.

The subject of units has received a good deal of attention from scientists engaged in various coöperative researches. While use of the metric system is in general growing in favor, and has been quite extensive in oceanographic work, there has been no common acceptance of its use in this field. There are good reasons for retaining the nautical mile as a unit of horizontal distances and the English fathom as a measure of depth. This convenient combination was exclusively used in oceanographic work published up to 1880. On the other hand, certain important dynamical and thermal computations are rendered simpler by the use of metric units. It is very important in any large program of Pacific ocean investigations, to agree on some uniform system of units, as well as on standardized methods of observing and collecting

CONCLUSION

In deciding on the best use to make of available means, experience shows that many observations of diverse kinds distributed over as large a region as facilities permit are especially valuable in providing data for the solution of important problems of interrelationship. In the interest of economy, especially at the beginning of the work, such extensive observations might have to be limited to a short period of time or to several short periods separated by longer intervals. In any case, aside from affording data adequate for preliminary solutions of various problems, such a procedure would indicate certain stations of peculiar value as indices of what is going on throughout great oceanic regions. At such critical stations as near an approach as possible to continuous observations should be carried on throughout a long period of time. Such continuous series are essential in investigations of periodic variations, annual anomalies, relations of climate to oceanic conditions, and are of great value in providing standards for comparison and interpolation in other less continuous series, covering extensive areas. Merely fragmentary, haphazard work, although of some value, is in general inefficient and unsatisfactory, especially from the standpoint of coördination and interpretation or the solution of definite problems.

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A SINKER METHOD FOR THE DETERMINATION OF SPECIFIC GRAVITIES

By N. W. Cummings, Assistant in Oceanography at the Scripps Institution

The oceanographic work being done at the Scripps Institution requires the accurate determination of the specific gravities of several thousand water samples a year. The results are of little value unless the error of a single determination is less than two thousandths of one per cent. To attain this degree of accuracy without consuming undue time is a problem that has engaged the attention of several oceanographers. Nansen (1893-1896) in his lengthy discussion of the use of the hydrometer lays stress on the errors caused by variation in surface tension. He shows that unless great care is exercised, errors as large as 0.0003 in the specific gravity are liable to occur. The use of hydrometers is also discussed by Helland Hansen (1911-1912). Jakob Schetelig (1901) gives a detailed description of the use of the total immersion hydrometer proposed by Nansen. Lamb and Lee (1913) describe a total immersion hydrometer controlled by an electromagnetic field of known intensity. It is said that with this instrument the specific gravity of dilute solutions can be determined accurately to the eighth decimal place. J. Y. Buchanan (1919) describes the hydrometer that he used on the Challenger expedition. A method has been developed at the Scripps Institution which makes it possible to run about thirty samples and to correct each specific gravity to the value corresponding to 0° all within one hour. Since specific gravity determinations are common in many kinds of work, a description of this method may be of somewhat general interest. For a brief description of the method as it was first employed, see Michael and McEwen 1915.

The accompanying photograph (figure 1) shows the arrangement of the apparatus. A glass sinker *S* having a volume of about 25cc and a weight of about 35g is suspended from the left arm of the balance and is immersed in the sample of water, which is held in a specially designed container. The sample is syphoned over from the collecting bottle to the container up to the level of the overflow which discharges into the tube *T*. After the determination is made the sample is withdrawn through a tube *e* leading from the bottom of the containing

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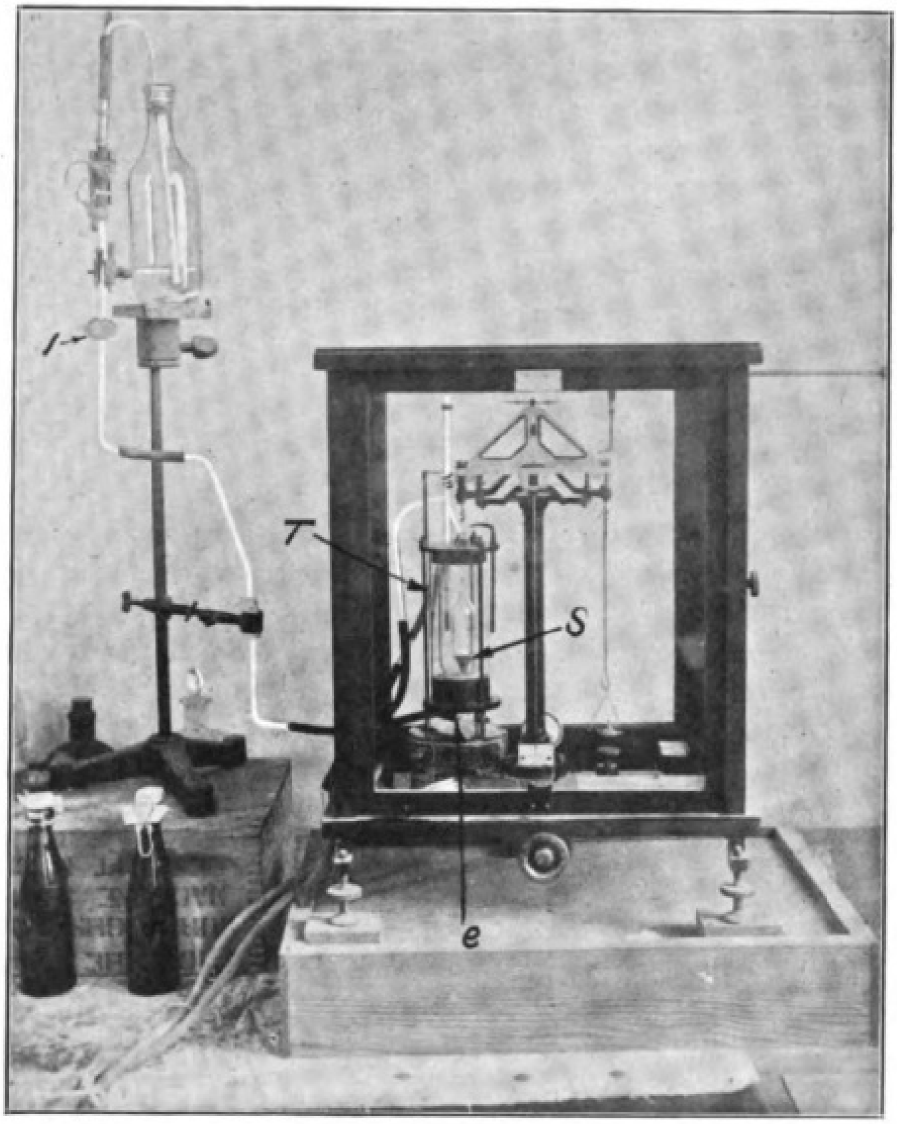


FIGURE 1. Apparatus for the determination of specific gravity.

vessel. It is thus possible to introduce and remove the sample without in any way disturbing the apparatus. The flow in and out is controlled by the stop-cocks *1* and *2*. (No. 2 is near the lower end of the rubber tubing and is not shown in the figure.)

The computations are made with the aid of a table, the principle of which is illustrated by Table II, which was computed on the assumption that the volume of the sinker is exactly 25cc. The work was done on an adding machine and hence its numerical accuracy throughout can be absolutely assured by a very rapid inspection. It requires about thirty minutes to print a sheet similar to that shown in Table II.

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The explanation is as follows:

If ρ is the density of any sample at the temperature of determination, V the volume of the sinker, and B the buoyant force exerted on the sinker, then

$$\rho V = B \qquad (1)$$

In this equation V is a function of temperature, and ρ a function of both temperature and salinity.

Differentiating (1), and solving for $d\rho$ we have,

$$d\rho = \frac{\delta B}{V} - \rho \frac{\delta V}{V} \qquad (2)$$

This equation expresses the change in ρ accompanying infinitesimal changes in B and V. It also gives the change in ρ that *would* accompany any *finite* change in B and V *if* the rate of change of ρ with B and V were constant over the interval. It is evident from equation (1) that the rate of change of ρ with respect to B is constant, and in our observations the magnitudes are such that no appreciable error is introduced by assuming the rate of change with respect to V to be constant also. In other words, it is assumed that V may, without undue error, be regarded as a constant divisor even though the differential δV is of the same order of magnitude as $d\rho$. This statement can be verified thus:

Solve equation (1) for ρ and let B_d represent the buoyancy exerted by distilled water having density ρ_d. Then the difference between the density of distilled water and that of any particular sample of sea water is given by

$$\rho - \rho_d = \left(\frac{B}{V} - \frac{B_d}{V}\right)$$

from which may be obtained

$$\rho = \frac{B - B_d}{V} + \rho_d$$

if V has the same value in the two determinations.

Now, the greatest error that can be caused by regarding V as a constant divisor will occur when B has its greatest value, and for a 25cc sinker this makes $B - B_d$ approximately equal to

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.75g. Differentiating with respect to V and substituting .75g for $B - B_d$ gives

$$\frac{d\rho}{dV} = \frac{B - B_d}{V^2} = \frac{.75}{625} = .0012$$

This means that a change of .01cc in V produces a change of approximately .00001 in ρ, or in other words, that if an error of .00002 is allowed, any value of V may be used which does not differ by more than .01cc from the true value, provided that the same volume is used in the determinations of both B and B_d. If the volume is not equal in the two weighings, then a correction must be applied which corresponds to the second term of equation 2, but in this term also an error of .01 in V is permissible, because ρ times the change in V is less than $B - B_d$. In practice, the volume does not change by more than .01cc between 10° C and 30° C, therefore from the foregoing discussion the differentials $d\rho$, δV and δB in equation (2) can, without too great an error, be treated as finite increments. The following equation is then a sufficiently close approximation:

$$\Delta \rho = \frac{\Delta B}{V} - \rho \frac{\Delta V}{V} \qquad (3)$$

We may therefore proceed as follows:

(1) Find the weight needed to balance the sinker in distilled water at the known temperature Θ.

(2) Find the weight needed to balance the sinker in a sample of sea-water of known temperature t, but unknown density.

(3) Compute $\Delta \rho$ from equation 3, regarding ΔV as the total thermal expansion of the sinker in passing from temperature Θ to temperature t.

(4) Add the result to the density of distilled water at temperature Θ as obtained from standard tables.

(5) Regard the sum so obtained as the true density, $S^t/04$ of the sea water at the temperature t.

The advantage of thus basing the computation on the density of distilled water is that it permits the use of an approximate value of the volume without undue sacrifice of accuracy. If the weighing in distilled water is so controlled as to make Θ exactly 20°, then ΔV becomes equal to $\xi V (t - 20)$ where ξ is the coefficient of cubical expansion of the material of the

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sinker. Though control within a sufficiently small temperature departure is impracticable, the desired result can be obtained by making weighings at convenient temperatures in the vicinity of 20° and reducing to 20° by the aid of equation (3), and the table from which the density of distilled water for various temperatures can be found.

Since ξ V is a function of temperature and nothing else, the procedure outlined above is equivalent to computing density from the equation

$$\rho = \rho_d + \frac{W_d - W}{V} + \rho \xi (20-t) \qquad (4)$$

where ρ_d is the density of distilled water at 20°, W_d the weight needed to balance the sinker in this water and W the weight needed to balance it in sea-water. It will be convenient to substitute for ρ the symbol $S^t/04$. The weight, W, equals C-B, where C is a constant pertaining to the apparatus.

In order to reduce the density of sea-water as determined from either equation (3) or (4), to the density at 0°, denoted by $S^0/04$ it is necessary to add a certain correction depending on both density and temperature. In his Hydrographische Tabellen, Knudson (1901) gives this correction, which he calls D, for a wide range of temperatures and densities. An investigation of the relation that D bears to temperature and $S^t/04$, as shown by these tables, revealed the fact that it is possible with the aid of equation (4) to construct table II by following a simple routine, and still preserve the required accuracy.

As a preliminary step, table I should be constructed by proceeding as follows:

(1) Compute $S^0/04$ for W_d-W=500 mg. and t equals 20°. The absolute values of W_d and W depend of course on the constants of the apparatus, but their difference only on $S^0/04$, t and V.

(2) From equation 3 compute the change in $S^t/04$ that would accompany an increase of 10 mg in W_d-W. If V equals 25 cc, this change in $S^t/04$ is obviously 40.[3]

(3) From Knudsen's tables find the change in D that accompanies the change in $S^t/04$ found in step 2. If the result

[3] For convenience, Knudsen expresses specific gravity by a number obtained by dropping the 1 to the left of the decimal point and then moving the decimal point three places to the right. We find it more convenient still to move the point five places to the right, instead of three.

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of step 2 is found to be 40, then the result of step 3 will be 2.4.

(4) Add the results of steps 2 and 3. The sum is the total increment in S °/o4 that accompanies a change in W_d-W of 10 mg. It so happens that this increment can be regarded as a constant for a very wide range of values of S ᵗ/o4.

(5) With the adding machine put 500 in the upper left hand corner of the sheet. Add 10 and subtotal; add 10 again and subtotal, and so on until the desired range has been covered.

(6) Just to the right of the 500 print the value of the S °/o4 corresponding to $W_d—W = 500$ mg. and $t = 20°$. Add the result found in step 4. The sum is the value of S °/o4 corresponding to 510 mg. and $t = 20°$. Repeat the process until the value of S °/o4 corresponding to each weight has been found.

TABLE I.

500.00	2,118.00	600.00	2,543.00	700.00	2,967.00
10.00	42.40	10.00	42.40	10.00	42.40
510.00 s	2,160.40 s	610.00 s	2,585.40 s	710.00 s	3,009.40 s
10.00	42.40	10.00	42.40	10.00	42.40
520.00 s	2,202.80 s	620.00 s	2,627.80 s	720.00 s	3,051.80 s
10.00	42.40	10.00	42.40	10.00	42.40
530.00 s	2,245.20 s	630.00 s	2,670.20 s	730.00 s	3,094.20 s
10.00	42.40	10.00	42.40	10.00	42.40
540.00 s	2,287.60 s	640.00 s	2,712.60 s	740.00 s	3,136.60 s
10.00	42.40	10.00	42.40	10.00	42.40
550.00 s	2,330.00 s	650.00 s	2,755.00 s	750.00 s	3,179.00 s
10.00	42.40	10.00	42.40	10.00	42.40
560.00 s	2,372.40 s	660.00 s	2,797.40 s	760.00 s	3,221.40 s
10.00	42.40	10.00	42.40	10.00	42.40
570.00 s	2,414.80 s	670.00 s	2,839.80 s	770.00 s	3,263.80 s
10.00	42.40	10.00	42.40	10.00	42.40
580.00 s	2,457.20 s	680.00 s	2,882.20 s	780.00 s	3,306.20 s
10.00	42.40	10.00	42.40	10.00	42.40
590.00 s	2,499.60 s	690.00 s	2,924.60 s	790.00 s	3,348.60 s
10.00	42.40	10.00	42.40	10.00	42.40
600.00 *	2,542.00 *	700.00 *	2,967.00 *	800.00 *	3,391.00 *

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TABLE II.

	630.00		640.00		650.00
20	2,670.00 s	20	2,713.00	20	2,755.00
	24.88		24.98		25.08
21	2,694.88 s	21	2,737.98 s	21	2,780.08 s
	25.88		25.98		26.08
22	2,720.76 s	22	2,763.96 s	22	2,806.16 s
	26.88		26.98		27.08
23	2,747.64 s	23	2,790.94 s	23	2,833.24 s
	27.88		27.98		28.08
24	2,775.52 s	24	2,818.92 s	24	2,861.32 s
	28.88		28.98		29.08
25	2,804.40 *	25	2,847.90 *	25	2,890.40 *

(7) From equation 4, compute the change in $S^{t}/o4$ that accompanies an increase of 1° when the weight remains constant.

(8) From Knudsen's tables find the change in D that accompanies a change in temperature from 20° to 21° at the value of $S^{t}/o4$ corresponding to the initial value of $S^{o}/o4$.

(9) Find the algebraic sum of the result of steps 7 and 8. The result is the total increment in $S^{o}/o4$ that accompanies a change in temperature from 20° to 21° when the weight remains constant.

It will be found by an examination of the tables that this increment is a function of both temperature and $S^{t}/o4$, or in other words, it is a function of temperature and weight needed to balance the sinker. It was found, however, that in the case of sea-water, this increment, which may be denoted by [D], could, without serious error be regarded as varying in a rather simple and regular way. It increases by 1.0 for each degree rise in temperature and 0.1 for each 10 mg. increase in W_d-W. It is therefore obvious how table II was constructed. The numbers 630, 640, and 650 along the upper part of the table are values of W_d-W. In the column directly under each of these numbers are the values of $S^{o}/o4$ corresponding to the weight at the top of the column and the temperatures at the left. The smaller numbers in this column are the values of [D]. They were printed

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so as to facilitate interpolation for fractions of a degree; ξ was assumed equal to .000031.

For any solution other than sea-water, the value of [D] will have to be determined from appropriate tables. It is probable, however, that for almost any solution, some such simple mode of variation as that found for sea-water can be discovered.

The most satisfactory way to check the table is to choose any weight and temperature within its range, compute the corresponding $S\,^{0}/04$ by some standard method, apply Knudsen's correction as taken directly from his tables and compare the result with that obtained from the computed table. This was done for several values of both arguments, and while there are some discrepancies, they are all within two thousandths of one per cent, which is about the limit of accuracy of the observations under ordinary working conditions. It is believed that most of the work is accurate within .001 of one per cent, i.e., to 1 in the fifth decimal place of the number expressing the true specific gravity.

It will be observed that the weights given in the table increase by intervals of 10 mg. but by the proper adjustment of sensibility and a proper choice of rider, weight interpolation is eliminated. It is evident from equation 4 that 1 mg. of weight makes a difference of 4 in the $S\,^{t}/04$. From Knudsen's tables it is found that an increase of 100 in the $S\,^{t}/04$ corresponds to an increase of .06 in D, and therefore an increase of 4 in $S\,^{t}/04$ will cause an increase of .24 in D. One mg. therefore causes an increase of 4.24 in $S.\,^{0}/04$. If then the sensibility is so adjusted that 1 mg. corresponds to 4.2 divisions, then the pointer will give directly the increment that must be added to the $S\,^{0}/04$ corresponding to the weights in order to give the true $S\,^{0}/04$ as far as weights and pointer are concerned. For this purpose the right end of the pointer scale should be regarded as zero. It may be more convenient in some cases to make the sensibility half as great and multiply the pointer reading by two.

Since an increase of 1 mg. accompanies an increase of 4.24 in $S\,^{0}/04$ an increase of 12 mg. will accompany an increase of 51, or approximately 50 in $S\,^{0}/04$. Consequently, if a 12 mg. rider is used with a balance designed for a 10 mg. rider, then the rider reading multiplied by -5 will give the increment in $S\,^{0}/04$ due to the position of the rider. The rule for finding $S\,^{0}/04$ is therefore as follows:

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(1) From the table find the basic number corresponding to the weight on the pan, and the next lowest exact degree, as arguments.

(2) Correct for the fraction of a degree by simple interpolation. (All temperatures should be read to 0.01°.)

(3) Add the pointer reading, or twice the pointer reading according to which sensibility is chosen.

(4) Add -5 times the rider reading.

The interpolation can be done with a slide rule, or the whole calculation can be done on a small adding machine, or if desired, auxiliary tables can be made to eliminate the necessity of interpolation. Since the rider can always be placed on a multiple of 2 the calculation by the use of the auxiliary table can be done mentally. Moreover, all the samples in any one group can be brought to practically the same temperature before they are run, so that only a small range of the table is required for the group.

It should be remembered that the tables presented herewith are intended merely to illustrate the method of development. They cannot be used for actual computation, unless the volume of the sinker is exactly 25 cc and its expansion coefficient .000031. The author expects to publish in the near future, certain key tables which can be used to facilitate computations with any glass sinker of approximately 25 cc volume.

The writer is greatly indebted to Dr. G. F. McEwen, Oceanographer of the Scripps Institution, and also to the late Mr. E. L. Michael formerly zoölogist at the Institution, for their many helpful suggestions.

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REMARKS ON OCEANOGRAPHICAL RESEARCHES IN JAPAN

By N. Yamasaki

It is my great pleasure to have an opportunity here to speak a few words on the oceanographical researches in Japan. As you know, the Japanese archipelago consists of a long chain of islands, which forms a barrier off the eastern coast of the Asiatic continent, extending between the latitude of Cuba to the south, and that of Newfoundland to the north. It faces the mighty oceanic basin of the Pacific to the east and the depressed seas of Okhotsk and Japan and the shallow sea of China to the west. The coast line of the archipelago is generally well developed. Every island is indented with innumerable bays and inlets, surrounded by rocky bluffs and sandy beaches. Thousand of isles and rocks are scattered near the coast, especially in the famous inland sea of Setouchi.

The warm Japan current, Kuro-siwo or black current, so named from its beautiful blue-black tint, washes the southwestern coast of the archipelago, while the cold Chishima current flows along the northeastern coast, just as the currents of Florida and Labrador are doing along the coast of America. Tsushima current, a branch of the Kuro-siwo, enters the Sea of Japan and affords moisture and warmth to the northwest coast of the mainland, which is exposed to the chilly northwest monsoon from Siberia in winter. Liman current, one of the two smaller cold currents along Sakhalin, flows southwest near the coast of the Asiatic continent. The course and boundaries of some of them are often changeable. Tidal streams are very significant, especially along the coast of the Inland Sea.

Various lines of the oceanic highway run on our water. The traffic is increasing with great rapidity in recent years. There are also many fields for fisheries. Abundant quantities of our foodstuffs and fertilizer are supplied therefrom. The sea is a home likewise a land for those who live on the islands. It forms the basis of their life. They are very directly concerned with it and they want much knowledge of it. Our oceanographical investigations were made at first by the Hydrographic office of the Navy Department. The surveying, sounding and charting were done year by year, during this half century, and has resulted in about 2000 published charts. Among

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them 500 are original surveys of Japanese waters and approaches; the others are translated or compiled from various sources. About 10 years ago other researches were undertaken by the Bureau of Fisheries of the Department of Agriculture and Commerce. Systematic investigations of the currents, temperature of water of various layers, amount of salinity and other features are in progress in the neighboring seas of Japan for the special purpose of developing the fisheries. On these subjects Prof. Kishinouye will give you some information in the section meeting. I am also very glad to infrom you that we have established a marine observatory in Kobe. It will begin its work from this year, and I believe that it will give many advantages to navigators as well as to men of science. I hope that the future cooperation of this work with that being done by other countries will promote scientific knowledge in the northwestern Pacific.

I can not here omit to say that the utilization of charts is nowadays extensively developed. Scientists, especially physiographers study these charts before they treat the topography of coast lands. The features of these lands have in general an intimate relation to that of the sea floor. One who looks upon a lofty peak of the great mountain chains surrounding the Pacific will not neglect to look down to the abysmal depths of the profound troughs along the coast. Geologists will investigate the nature of the bottom deposits. Tuscaroro Deep, 8500 metres in depth, and Nero Deep, 9636 metres in depth, are perhaps of no use to the navigators, but they are of great interest to geographers and geologists. Fishermen will learn from a chart the existence of a certain shallow bank where abundant varieties of fish are gathering. They will also seek on the chart the position of currents which afford a living place for the migration of fishes. Cableships will easily find on a chart, a submarine plateau, which is suitable for laying down their cable. Charts are no longer for the use of navigators only, but they are used extensively by the public. Our hydrographic office has prepared already for this purpose cheaper and portable prints on thin paper. Many teachers use these charts for educational purposes and it is not uncommon to find these sheets in travelling cases of school boys on their summer vacation. The charts were made formerly for navigators, but the extension of their use will require some improvement of their

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contents, especially on the description of bottom deposits. I will discuss these special points in the session of geography this afternoon.

[As presented at the Conference this paper was illustrated by many charts and diagrams showing in detail the character and extent of oceanographic work in Japan.—*Committee on Publication.*]

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OCEANOGRAPHY AROUND AUSTRALIA

By Geo. W. Halligan, Late Supervising Engineer and Hydrographer, New South Wales

(Presented at the Invitation of the Committee on Program.)

The work done in exploring the surface, subsurface and tidal currents, and in investigating the tidal phenomena around Australia, since Captain Cook took possession of the east coast in 1770, has been very sporadic; no organized scheme for carrying out this most important work has yet been attempted. Vancouver who entered and named King George's Sound in 1791, Flinders and Bass, who extended the discoveries of Cook on the east coast in 1798, followed by Murray in 1802, took careful and reliable observations at the various places visited by them. During 1802-3 Captain Matthew Flinders in H. M. S. *Investigator* explored the coast between Sydney and the Gulf of Carpentaria, and completed his remarkable voyage by sailing completely round Australia. About the same time the French explorers Baudin and Freycinet in the *Geographic* and *Naturaliste* examined the northwest and west coasts. The northern and northwestern coasts were charted by Captain King in 1820-4, followed by Captains Wickam and Stokes in 1837-43 and Captain Denham in 1858. Since 1872 the Admiralty has carried out detached surveys, mostly on the north and northwest coasts but a large part of the shores of Australia are still very imperfectly charted, both as regards the outline of the land and the trend of the currents and tidal streams. Beside the above named a great number of isolated observations of the direction and velocity of some of the surface currents have been made by chance visitors or exploring expeditions at odd times, such as Captain Sir James Ross in 1841, the French frigate *La Venus*, in 1832, Captain Wilkes in 1840, H. M. S. *Challenger* in 1874, the U. S. S. *Tuscarora* in 1874-6 and H. M. *S. Gazelle* in 1875.

The splendid work, thus briefly epitomized, provides us with sufficient information to outline in general terms the trend of most of the oceanic surface currents around Australia, and provides a groundwork upon which subsequent investigations may be built. But it is necessary to remember that the observations were confined, in most cases, to one season of the year, so that the results must be regarded as applying to that par-

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ticular time and place only. It will be evident that, from the paucity of the observations available, any conclusions arrived at, concerning the ocean currents around Australia must be regarded as more or less tentative. A good deal of time and energy has been uselessly expended in the endeavor to ascertain the drift of ocean currents, by throwing bottles overboard, each containing a memorandum setting forth the locality and date of the start of their ocean journey. At some subsequent date some of these are found on distant shores, and are forwarded to the senders, who compare the distance and direction travelled from a comparison of the dates and a knowledge of the shortest distance between the starting point and the place where the bottle was picked up. The information gained may represent to some extent the direction of the dominant wind between the two points named, but obviously is no indication of any value as regards oceanic currents. Strange to say the custom is still continued, but as the results are not only erroneous but distinctly misleading, the practice should be stopped.

A proposal is now before the Commonwealth Government to carry out the pioneering work in connection with oceanic current and tidal work around the continent, from a small ketch of dimensions about 80 feet by 16 feet by 8 feet draft. The author offers to supply all the necessary scientific equipment and his own services for 3 years free of cost, if the Government will provide the vessel and the required crew.

The primary object of the expedition will be the investigation of the ocean currents, and this will be done by observations of the temperature, salinity and density of the water on section lines approximately normal to the coast, at intervals depending upon the depth and configuration of the ocean bed in the vicinity; samples of the plankton, nekton and marine algae will be collected, and examined on board, as the information gained from such sources is often the most important factor in determining the origin and direction of flow of ocean currents. The length of the sections will probably vary from 50 to perhaps 200 miles, and the depths from 10 to 1000 fathoms.

The vessel will be moved from north to south, or from east to west of the continent, as the conditions become favorable or otherwise. At present it is only possible to say that very little oceanographical work will be done within the tropics between the months of November to April, whereas that period

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will probably be found to be the most favorable on the east, southeast, and part of the south coasts.

I propose to explore thoroughly the surface, subsurface, monsoonal and tidal currents where such exist, mainly on the lines adopted by the *Challenger*, *La Venus* and *Tuscarora* expeditions using of course, the most up-to-date instruments and appliances.

The investigation of the tidal phenomena from Great Sandy Cape through Bass Strait to Cape Leeuwin will probably be found to be comparatively simple, but within the great Barrier Reef and on the north, northwest and west coasts some difficulty is anticipated. It will here be necessary to differentiate between the oceanic and the tidal currents, and the indrafts and outdrafts at the numerous gulfs and bays must be studied.

A careful investigation of the positions of the tide-gauges used on the coast surveys will be made, in order that accurate co-tidal lines may be drawn around Australia. Up to the present nothing approaching accuracy in this important matter has been attained, and it is anticipated that the examination now projected, will help to determine which of the rival theories of the origin of the world tidal phenomena is correct.

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SOME EFFECTS PRODUCED BY COMMON CHANGES IN NATURAL WATERS

BY R. C. WELLS

The characteristics of natural waters, in so far as they are due to other substances than pure water, can usually be ascribed to two factors, first, the nature of the contained material and, second, the quantity in unit volume, or concentration of that material. On careful examination it appears that the second factor, the concentration of contained material, is the principal factor to be considered, inasmuch as most waters contain at least traces of all the common constituents, from which it follows that the mere presence of a certain constituent is generally of less significance than the amount of it.

When natural waters remain in contact with the different kinds of matter that make up the earth's crust they tend to become saturated with the various constituents with which they come in contact. In some cases the material dissolves so as to be recoverable, like common salt, in other cases it is partially decomposed, like feldspar. In some cases the rate of solution or decomposition is rapid, and in other cases slow. Meanwhile as chemical action goes on, physical changes occur. The principal changes of this sort are: (1) the water is warmed or cooled; (2) it is concentrated by evaporation, or diluted by "fresh" water; or (3) it mixes with another water.

Certain effects of these common physical changes are familiar to everyone, such as the solution or deposition of simple salts and the formation of chemical precipitates. On the other hand, many investigations in physical chemistry are constantly in progress which, although they are merely extended quantitative studies of similar changes under definite conditions, are not widely known and yet have obvious geologic application. This fact would seem to justify such discussion of the subject as a single short paper will permit.

EFFECTS OF TEMPERATURE CHANGES

A rise in temperature increases the solubility of most salts in water. The solubility of sodium chloride, however, does not change greatly with temperature, while the solubility of some salts decreases, as does also the solubility of gases with a rise of temperature. One of the most interesting cases of the latter

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behavior is that of calcium carbonate held in solution by an excess of carbon dioxide. As carbin dioxide is more soluble in cold water than in hot water, the parital pressure of the gas remaining constant, it follows that more calcium carbonate can be held in solution in cold water than in hot water, other conditions being unchanged. Thus in water in equilibrium with the atmosphere I find 81 parts of $CaCO_3$ per million at 0°C as compared with 60 parts at 20° and 40 parts at 47°; that is, the solubility is halved in passing from 0° to 47°. This range is just about the extreme range to which sea-water is ever exposed. The effect on the solubility of $CaCO_3$ is greater than that caused by a five-fold change in the partial pressure of CO_2 in the atmosphere, e.g., from 1 part to 5 parts in 10,000. In 1916 I suggested that the water of the Mississippi River, which flows southward, and therefore increases in temperature, should tend to become saturated with, or even to deposit $CaCO_3$ in its course, and such analyses as are available appear to confirm this observation. In the ocean, likewise, one would expect that $CaCO_3$ is being constantly transferred from the colder to the warmer regions. This action is influenced by several other factors, however, that are difficult to evaluate. For example, the water must lose its CO_2 before the $CaCO_3$ will tend to deposit, and there is apparently no way in which CO_2 can escape from deep water that never comes in contact with the air in its progress from the poles to the tropical regions—no way unless living creatures act as carriers. Moreover, even if $CaCO_3$ is transferred slowly in this way, the effect is more or less obscured by the effects due to mechanical agencies.

Lastly, in any case one rarely has to do with mere chemical precipitation—although this has been proved to occur in some localities—but rather with precipitation by organic agents. L. J. Henderson has found that some kind of organism is generally employed in any change of chemical potential however slight. In other words, before the extent of supersaturation becomes sufficient to produce well formed crystals of inorganic $CaCO_3$ some organism seizes on the material and secretes an organic product. The physical chemist can point out tendencies, but the final adjustment becomes a problem in biological chemistry. However, in some sea-water that had remained sealed up for several years in glass I was able to identify a slight precipitate that had formed as aragonite. Presumably its formation

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was caused by slow attack of the glass, the alkali of which would be expected to favor the deposition of calcium carbonate.

The effects cited for $CaCO_3$ must be similar for $MgCO_3$ or for dolomite, but in spite of several attempts I have not been able to get good solubility data for the magnesium compounds. However, F. W. Clarke and others have shown a most interesting relation bearing on this point, viz.—that the proportion of Mg to Ca in carbonate deposited by recent organisms varies from species to species. The chief contributors of Mg are the foraminifera, calcareous sponges, alcyonarians, echinoderms, and certain crustaceans. Moreover in any one of these groups the ratio of Mg to Ca is higher, the higher the temperature of the water in which the organisms grew. Thus for the crinoids the percentage of magnesium carbonate ranges from 8 to 12 per cent according to the temperature.

A problem on which quantitative data would be welcome is the question whether the lighter elements are in fact being very slowly transported by the agencies under discussion from localities bathed by cold waters to localities where warm waters prevail and from the depths of the ocean to sea level. If this occurs it appears that we have here a factor that might be worth considering in attempting to trace the direction of isostatic adjustments. It seems to be generally held that the great deeps of the ocean have maintained approximately their present position through many geologic periods whereas the continental formations have very generally been under sea level at one time or another. Whatever other results may have been produced by the agency suggested it appears that it must contribute somewhat to the loading of the coastal or shore areas in many places, especially in the tropics.

EFFECTS OF CHANGES IN CONCENTRATION

It is scarcely necessary to mention that solutions tend towards the saturated condition on concentration and away from it on dilution with pure water. We are accustomed to think of the atmosphere as the chief reservoir for evaporated moisture but in a Bulletin of the United States Geological Survey published in 1919, by R. V. Mills and myself, we discussed the condition under which natural gas will cause evaporation even at depths. Expanding gas may afford the necessary space to cause sufficient evaporation to clog up gas wells with salt. It appears that similar action would occur even more easily at

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great depths on account of the higher temperature. The geologic effects to be expected at depth must depend greatly on the relative quantities of gas and water. Wherever the volume of gas reaches the order of the volume that the water would occupy as vapor the phenomena of evaporation, such as the occurrence of salt, are to be expected. This may in many cases explain the very common association of salt with natural gas and petroleum accumulations observed all over the world.

One of the oldest properties used to characterize solutions is their reaction to test papers, or indicators. In modern terms capable of expressing quantitative relations this means their hydrogen-ion concentration. The ions of pure water, which is a neutral substance, are $H+$ and $OH-$. Solutions containing substances that develop more hydrogen ions than does pure water are considered to have an acid reaction. Since the product of the two concentrations $[H+]$ $[OH-]$ is a constant quantity solutions having an excess of hydroxide ions, i.e. alkaline solutions, must necessarily have a deficit of hydrogen ions, so that a statement of the hydrogen-ion concentration suffices to characterize any solution as far as this particular property is concerned, which, however, takes no account of the quantity of substance present causing this property.

Let us consider briefly the effect of changes in concentration on the hydrogen-ion concentration of certain solutions. Alkaline waters containing carbonates are extremely common in nature and similar waters containing sulfides fairly common. These two classes of waters behave similarly. The effect of dilution is to make them more alkaline (owing to hydrolysis); conversely, on concentration they become less alkaline and more acid. This behavior has been found as the result of laboratory study. In the field there are complications that may modify or completely reverse these effects. For example, natural waters are not diluted with pure water, but with water containing a little CO_2, which tends to counteract the alkalinity that would be caused by dilution. Again, on concentration, natural waters generally lose part of their dissolved CO_2 or H_2S, thus tending to become more alkaline in opposition to the effect caused solely by concentration. These examples are sufficient to show what a complex and mobile phase a natural solution is, subject as it is to almost infinite variation caused by changes in pressure, temperature and the concentration of its constituents.

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EFFECTS OF ADMIXTURE WITH SALT WATER

Starting with dilute alkaline sulfide or carbonate waters of the kind just considered I have found that the addition of solid salt to them makes them slightly more acid. When the salt is added as a solution, however, as happens when fresh water mixes with sea-water this effect is again more or less counterbalanced by the change of volume. In general, after admixture each constituent will have a different concentration than it had in either water before admixture. Thus when one volume of average Mississippi River water unites with one volume of Gulf of Mexico water the molecular concentrations of the sea-water constituents are about halved, as illustrated by the figures for the calcium and chloride concentrations shown in the following table:

Concentration changes on mixture of equal volumes of average Mississippi River water and Gulf water.

	[Cl]	[Ca]	[HCO_3]
Mississippi water	0.0029	0.00077	.00186
Gulf water	.545	.0108	.00202
Mean	.274	.0058	.00194

The bicarbonate concentration, on the other hand, is about the same in both waters. I have evaluated the carbonate-ion concentration of sea-water but unfortunately no data are available for the river water so that it is impossible to compare the "solubility-product" values of calcium carbonate for the two waters. It would be somewhat difficult to make the necessary evaluation for the river water but I think that an attempt should be made to obtain at least an approximate figure as it is only in this way that further advances of a quantitative nature are possible.

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PHYSICO-CHEMICAL INVESTIGATION OF THE WATER OF THE PACIFIC OCEAN[1]

By R. C. Wells

Most writers on sea water content themselves with a statement of the essential uniformity of the composition of the oceanic salts, although admitting of course a considerable variation in the concentration of the salts. Although this doubtless represents the situation very nearly, there is little available evidence to show whether or not slight differences exist between the waters of the Pacific and other ocean waters. Some differences have been mentioned in the literature; for example, Buchanan's determinations of half-bound carbon dioxide run lower for Pacific waters than for Atlantic waters of the same temperature. The connection of the Pacific with other oceans is greatest with that of the Indian ocean south of Tasmania, less with the Atlantic south of Cape Horn and very slight elsewhere, so that it is not reasonable to expect that the Pacific may have slight characteristics of its own, especially as every ocean has variations of salinity, dissolved gases, temperature, and density, within its own basin.

Just as hydrographic data on the depths of the Pacific are relatively scanty, data on the temperature, salinities, dissolved gases, etc., are even more scanty, so that estimates of the volume, mean temperature and other characteristics of the Pacific can not be considered at all accurate. Some determinations of the salinities and hydrogen-ion concentrations of Japanese waters have been made by the Bureau of Fisheries of Japan under direction of Prof. Kishinouye but the results do not seem to be known as yet in the literature. In addition to this work there are the recent papers by McEwen and Mayor and the older work of Murray.

The writer was able to make a few determinations of the hydrogen-ion concentration of Pacific Ocean water on the trip from Honolulu to San Francisco in August, 1920, using the indicator cresol red and standard color tubes whose hydrogen-ion concentrations had been determined by electrometric measurements in the chemical laboratory of the United States Geological Survey at Washington, D. C. The results are given in

[1] Contributed by permission of the Director of the United States Geological Survey.

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the accompanying table, in which the temperatures have been corrected by an accurate thermometer.

Determination of Hydrogen-ion concentrations of sea water made between Honolulu and San Francisco, August, 1920.

Date	Time	Location		Temp. °C	Ph	Remarks
Aug. 5	10.00 a.m.	Two miles off Honolulu		26.4	8.15	Fair
Aug. 25	4.30 p.m.	22°30′ N	156°40′ W	26.3	8.13	Cloudy
Aug. 26	7.30 a.m.	23°40′ N	153°50′ W	25.5	8.13	N.E. wind
Aug. 26	2.30 p.m.	25°00′ N	152°00′ W	24.9	8.08	N.E. wind
Aug. 27	1.30 p.m.	28°50′ N	146°20′ W	23.9	8.17	N.E. wind
Aug. 28	7.45 a.m.	30°40′ N	142°05′ W	22.4	8.14	N. wind
Aug. 28	1.40 p.m.	31°40′ N	140°20′ W	22.0	8.13	Less wind
Aug. 29	10.30 a.m.	33°40′ N	135°05′ W	20.8	8.08	Smooth
Aug. 29	12.00 noon	33°50′ N	134°48′ W	21.0	8.05	Smooth
Aug. 29	6.00 p.m.	34°25′ N	133°05′ W	20.6	......	Smooth
Aug. 30	8.45 a.m.	36°00′ N	128°20′ W	18.3	8.10	Smooth
Aug. 30	4.30 p.m.	36°50′ N	127°00′ W	16.1	8.10	Smooth

It may be stated that these Ph determinations appear to run somewhat lower than those recorded by Mayor (Proc. Amer. Phil. Soc., vol. 53, p. 150, 1919), but the slight variations are exactly similar to those found by him. On the whole there is not the variation with temperature which the writer had expected to find. The average of all determinations is 8.11. Hence as far as the evidence goes it appears to indicate a monotonous uniformity in the quality of the water, undisturbed either by adjustments with the atmosphere according to temperature or by regional plant or animal processes.

The water collected Aug. 5, 1920, outside Honolulu harbor was found to contain 0.0884 gram carbon dioxide per liter and the alkalinity caused by carbonates and bicarbonates was found to be 0.00206 equivalents per liter. Unfortunately, however, it is not absolutely certain that the water was not somewhat affected by its transfer to Washington in a metallic container and it would be better to rely on analyses made nearer the source where possible, with the object of avoiding any error caused by the containing vessel. The above results agree essentially with those found by the writer for water of the Gulf of Mexico (Year Book No. 18 of the Carnegie Institution of Washington, p. 195), although the carbonate titration alkalinity is slightly lower.

In conclusion it may be remarked that the Hawaiian islands are very favorably located for the study of sea water, as unusually deep water is to be found within a day's run from the coast in several directions.

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STATUS OF AREAL GEOLOGICAL MAPPING IN THE PACIFIC REGION

INTRODUCTION AND NOTES ON ANTARCTICA, OCEANIA, THE EAST INDIES, MALAY PENINSULA, AND FRENCH INDO-CHINA

By T. Wayland Vaughan

INTRODUCTION

To those interested in the history of attempts to compile or to have compiled geological maps of the world or of large parts of the world, the address of Emmanuel de Margerie entitled "The geological map of the world,"[1] delivered before the International Geological Congress at its Toronto meeting, is of particular importance for it is an excellent history of the attempts to compile such maps and gives a résumé of the status of the geological map of the world in 1913. De Margerie in this address advocated the preparation of geological maps of Asia with its outlying islands, Africa, South America, and Australia, "each with its own projection center, drawn on a uniform scale of 1:5,000,000, and following broadly the lines of the Geological Map of North America," compiled by Bailey Willis and George W. Stose. It is gratifying to geologists in general that so much progress has been made in geological mapping since de Margerie delivered his address. There have been published geological maps of large areas, such as that of Western Australia on a scale of 1:3,168,000 by Gibb Maitland; that of the Dutch East Indies on a scale of 1:2,500,000, by Abendanon; of parts of China by the Tokyo Geographical Society and the Chinese Geological Survey, under the direction of Dr. V. K. Ting, is engaged in extending geological knowledge of that republic. The geological map of Brazil by Branner is on a scale of 1:5,000,000. The total area of South America, according to the Century Atlas, is about 6,837,000 square miles, while that of Brazil is about 3,210,000 or only about 300,000 square miles less than half the total area of South America. It is probable that most of the data are now available for putting into effect the suggestion of

[1] Cong. geol. internat., XIIe session, Canada, Comptes Rend., pp. 173-187, 1914.

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de Margerie for maps of all the continents on a scale of 1:5,000,000.

There are certain suggestions in de Margerie's address that need to be emphasized. Two of these are contained in the following quotations:[2]

It is desirable to discriminate by means of appropriate symbols: (1) fresh water or subaerial deposits from those which are of marine origin; (2) districts where the strata have remained undisturbed from regions where they are more or less intensely folded.

With regard to a geological map of the world on a scale of 1:1,000,000, de Margerie[3] says:

The experience gained in preparing that Geological Map of Europe, both as regards its elaboration and its publication, has shown that it would be utterly impracticable at the present time to extend such a large scale (1:1,500,000) to other parts of the globe—not to speak of the scale of 1:1,000,000, which is becoming the standard scale for purely geographical purposes the world over, according to the plan originated more than twenty years ago by Professor Penck. That scale of 1:1,000,000, submitted in 1910 by Dr. G. O. Smith, Director of the United States Geological Survey, for the approval of the Stockholm Congress as the scale for the future Geological Map of the World, was unanimously rejected, as you know, without regard for future conditions.

Every person informed regarding the matter will admit that to construct a geological map of the world on a scale of 1:1,000,000 at the present time is an impossibility, for the necessary data have been acquired for only a minor part of the earth's surface. It is a safe assumption, however, that every geologist wishes that there were such a map and hopes that some day it will be constructed. The formulation of a plan for the realization of that hope and striving for the attainment of that ideal seem reasonable, although many years will certainly elapse before the desired end will be achieved. In fact, there will have to be fairly rapid progress to have such a map fifty years hence. But for considerable parts of the earth's surface the data are already available for a 1:1,000,000 scale map. Almost enough data have been accumulated to map the United States and most of the West Indies on that scale; a map of Japan has been published on that scale; and much of Australia has been mapped.

It was with consciousness of the magnitude of the undertaking that the members of the Section of Geology at the Con-

[2] de Margerie, Op. cit., p. 180.

[3] Op. cit., pp. 176, 177.

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ference in Honolulu passed the following resolution which was later adopted by the general Conference (See p. 40 of this volume):

Since it is in the interest of science and of value in the development of the natural resources of the different countries concerned, be it

Resolved, That the following maps of the Pacific region on the international scale of 1:1,000,000 be completed as expeditiously as possible: (a) A base map showing by contours or hachures as many topographic features as practicable; (b) A map showing geological formations or groups of geological formations; (c) A map showing mineral resources.

Since that part of the resolution relating to the base map seemed to belong more properly within the scope of the Section of Geography than within that of the Section of Geology, it was referred to that section for further action; and because areal geological maps should precede maps devoted to economic geological resources, attention was concentrated on areal geology.

But before proceeding to the discussion of the compilations on areal geology it is desirable to mention several compilations on economic geology. They are the Iron Ore Resources of the World,[4] the Coal Resources of the World,[5] and the World Atlas of Commercial Geology now being published by the United States Geological Survey. Part 1, Distribution of Mineral Production, of the last mentioned publication has been issued.[6]

As a preparation for the endeavor to advance areal geological mapping in the lands of the Pacific region a resolution favoring the compilation of data showing the present status of areal geological mapping in the region was adopted. The following geologists were requested to arrange for compilations on the areas following their names: Dr. J. Allan Thomson, New Zealand; Mr. E. C. Andrews, Australia; Dr. N. Yamasaki, China, Japan, and Korea; Dr. W. D. Smith, the Philippine Islands; Dr. T. Wayland Vaughan, Oceania, The East Indies, and North and South America.

As soon as possible after their departure from Honolulu the members of this committee began obtaining the data requested. At Dr. Allan Thomson's request Mr. P. G. Morgan, Director of the Geological Survey of New Zealand, prepared a statement on New Zealand. Mr. Andrews enlisted the cooperation of

[4] Cong. geol. internat., Stockholm, 2 qto. vols. and atlas, 1910.

[5] Cong. geol. internat., Toronto, 3 gr. 8vo. vols. and atlas, 1913.

[6] Atlas, qto., 13¾ by 10¼ in., 72 pp., 72 pls., 4 full page maps, Washington, 1921.

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Messrs. W. Baragwanth, Director of the Geological Survey of Victoria, Loftus Hills, Government Geologist of Tasmania; L. Keith Ward, Government Geologist of South Australia, and A. Gibb Maitland, Government Geologist of West Australia. Mr. Andrews himself naturally prepared the data for New South Wales as he is the Government Geologist for that State. Unfortunately no data were received from the Government Geologist of Queensland; therefore, I have attempted a compilation for it. Dr. Warren D. Smith has furnished a statement for the Philippine Islands; and Dr. N. Yamasaki prepared a statement, illustrated by a key map, for Japan, Korea and China. After my return to Washington, in compliance with a request I addressed to each, the directors of the Canadian and Mexican geological surveys agreed to have compilations made for Canada and Mexico. The statement for Canada is by Dr. Victor Dolmage of the Canadian Survey; and that for Mexico is by Señor Don Salazar Salinas, Director del Instituto Geologico de Mexico. Several of my associates within the United States Geological Survey kindly consented to help in the compilation. Mr. L. M. Prindle has supplied a valuable list of geological maps of Siberia, illustrated by a key map; Col. Alfred H. Brooks has prepared an authoritative statement on Alaska; and Mr. H. B. Sullivan has prepared a list of geological maps of South America, illustrated by a key map, similar to Mr. Prindle's compilation for Siberia.

As it was at first hoped that the compilations might be completed by the first of February, 1921, there did not seem to be sufficient time for correspondence with geologists in the Dutch East Indies, the Federated Malay States, and French Indo-China regarding the status of geological surveys in areas in the western Pacific with which they are especially familiar. Under the circumstances I wrote to Professor Molengraaff and Professor Brouwer at Delft and relied on their kind guidance for the Dutch East Indies, and for Antarctica, Oceania, the Malay Peninsula, and French Indo-China depended on my general knowledge of the geological literature of these regions and the facilities of the library of the United States Geological Survey. Correspondence with Dr. V. K. Ting, Director of the Chinese Geological Survey, was also impracticable. I undertook the compilation for the western part of the United States but had the advice and assistance of Messrs. David White, F. L. Ransome, Sidney Paige, G. R. Mansfield, and J. S. Brown in

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the task. I am also responsible for the statement on Central America and the West Indies, a region on the study of whose geology I have been engaged for many years.

The foregoing list indicates that the compilation here presented represents the work of a number of geologists, and I am confident that I voice the feelings of those present in Honolulu in expressing gratitude to those who have made successful an undertaking of considerable magnitude.

There were several difficulties in the execution of the program outlined for the compilation of the data on areal geological mapping in the Pacific region. The first was to define the boundaries of the Pacific region. As a part of the purpose of the geological investigations is to understand the geological history of the lands bordering the Pacific Ocean, as well as that of those rising from the floor of the basin proper, clearly information should be procured over areas extending far enough away from the ocean margins to render it reasonably assured that all the needed data would be obtained. For instance, it was decided to include all of Australia. In reply to a possible question as to the propriety of this procedure, it will be pointed out that the peculiar relations of the geologically very ancient buttress in southwestern Australia to those parts of the "Island Continent" that lie farther east and north are such that without due consideration of the geology of its southwestern part the geology of its other parts cannot be adequately understood. In Siberia information is presented as far westward as Lena River. In North America the eastern line follows approximately the eastern foot of the Rocky Mountains and all of Mexico and Central America are included. In South America the boundary logically should be placed at the eastern foot of the Andes, but as all South American countries except the Guianas, Paraguay, and Uruguay touch or almost touch the Andes, although some of them do not border the Pacific, data are given for the entire South American continent. India should probably have been included, for the Himalayan geosyncline is a key area in understanding the relations between the Pacific and Atlantic oceans in past geological time. As so much of the geological literature on India, particularly the geological maps, is concentrated in the excellent publications of the Geological Survey of India, and as those reports are accessible in all large libraries, mention of these

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publications appears to be sufficient for present purposes.[7] The treatment of the West Indies was a cause of perplexity because of the relations of the Caribbean Sea. At present the Caribbean Sea is cut off from communication with the Pacific Ocean and is in communication with the Atlantic. Looked at in some ways the Caribbean region may be considered as separate from both the Pacific and Atlantic Oceans, but looked at in another way it may be considered as belonging to both. From the standpoint of the history of the organisms in the Atlantic and Pacific basins and from that of the history of those geological features whose ages are determined by means of fossil marine organisms, knowledge of the geology of the West Indies is essential. The structural geology of the West Indies and some of the geological phenomena exhibited there, that are dependent on tectonic causes are intimately connected with similar features in Central America. For these, and other reasons, it is deemed advisable to include a statement on the West Indies.

Another difficulty in making the compilations was that those who undertook the work were greatly scattered. They were in New Zealand, Australia, the Philippine Islands, Japan, Canada, the United States, and Mexico. It was not practicable while several of us were together in Honolulu to draw up a definite program to be followed in the presentation of data and as it was desired to have the statements early enough for them to be published in the Proceedings of the Conference, preliminary correspondence regarding the matter was not feasible. There is, therefore, some lack of consistency in the different statements. This, however, is not a serious defect. A more serious defect has been inability to consult recent publications because of the interruption of communications and the suspension of the publication of bibliographies during the Great War. Recently published important works have not been received in Washington. For such reasons there may be omissions of references to important literature.

Although the data here presented show that a large amount of geological work has been done in the Pacific region, the need of additional geological surveys in areas of vast extent is made clear. Since geological surveys, because of the large expense required, depend for successful prosecution on governmental support, it is hoped that those countries that do not now possess

[7] Wadia's Geology of India for Students is a very convenient summary of the geology of India.

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such institutions may make provisions for them in the near future. The local governments of some areas, such as islands of small population and of no known geological resources of notable economic value, cannot reasonably be expected to support geological surveys; but some of these areas are scientifically important because knowledge of them is needed for the solution of larger problems of the earth's history. Geological investigations in areas of this kind, particularly small islands, will need support from private endowments or from the wealthier governments.

A review of the data here assembled leads to the hope that within a short time revised maps of the tectonic features of the Pacific region may soon be prepared. Sir T. W. E. David's paper on the tectonic features of Australia,[a] Brouwer's work on the Dutch East Indies,[a] and the studies of Alaska on which Brooks is engaged are achievements of value and a foundation of hope for the future. This subject is one appropriate for a future conference at which a plan for the work might be outlined. But the dating of the development of many tectonic features must for a considerable time be tentative..

An examination of the many published geological maps and perusal of much of the large quantity of extant literature reveals the unsatisfactory condition of many of the geological correlations within the Pacific region. It might be desirable to review the status of geological correlation in general within the region, for the purpose of providing for better systematized work on the problems involved. Brief summaries of the correlation of post-Cretaceous formations in the Pacific region form a part of the present volume, but these are not the only formations that need consideration.

The three suggestions embodied in the foregoing discussion may be succinctly stated as follows:

1. To endeavor to stimulate geological surveys within those areas for which data are deficient and for which there are at present no provisions for geological surveys.

2. To have revised maps of the tectonic features of the Pacific region prepared.

[a] David, T. W. E., Notes on some of the chief tectonic lines of Australia: Roy. Soc. New South Wales, vol. 45, pp. 4-60, 2 pls., 1911.

[a] Brouwer, H. A., Geol. overzicht van het oostelijk gedeelte van den Oost-Indischen Archipel: Jaarb. Mijnwez, Verhand. 46, deel 2. 1917.

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3. To arrange for a comprehensive discussion of problems of geological correlation within the Pacific region in order to bring about a better coördination of researches on such problems.

NOTE ON ANTARCTICA

Sir T. W. E. David and Raymond E. Priestly have recently published a large monograph on the geology of Antarctica[10] and it should be the first work consulted by those interested in the geology of that part of the world. The last chapter in this work is entitled "Notes of the general geological relations of Antarctica to other parts of the World." The second volume on the geology of the British Antarctic Expedition[11] contains on page vi, in the preface to the volume, the statement that it is intended in the near future to publish a bibliography of Antarctic geology by W. S. Dun.

Another work, Nordenskjold's Antarktis,[12] in which all of Antarctica is treated, is of much value. This work summarizes geological information on Antarctica up to 1913. Text figure 1 is a geological sketch map of Antarctica; figure 2 is a geological map of northern West Antarctica; figure 4 is a geological sketch map of the vicinity of Admiralty Strait; figure 5 is a map of the principal orographic features of South Victoria Land, after David and Priestley; plate 1 is a geological map of the vicinity of MacMurdo Sound (South Victoria Land), after H. T. Ferrar. Reed has summarized the geological features of the Falkland Islands, South Georgia, Graham Land, the South Orkney Islands, and the South Sandwich Islands, and given references to literature in his book referred to below.[13]

For the considerable information available on Antarctica geologists should be grateful, but more knowledge of that region is still one of the great desiderata of science, for only by such knowledge can some of the largest problems of earth history be satisfactorily solved.

[10] David, T. W. E., and Priestley, Raymond E., Glaciology, physiography, stratigraphy, and tectonic geology of South Victoria Land: Brit. Antarctic Exped. 1907-9, Geology, vol. 1, 318 pp., 95 pls., 67 figs., London, W. Heinemann, 1914.

[11] Contributions to the paleontology and petrology of South Victoria Land, 1916.

[12] Nordenskjold, Otto, Antarktis: Handb. region. Geol. Heft 15 vol. 8, part 6, 29 pp., 1 pl., 6 text figs., 1913.

[13] Reed, F. R. C., Geology of the British Empire, pp. 160-167, 1921.

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GEOLOGICAL MAPPING IN OCEANIA

A good summary of knowledge of the geology of Oceania up to 1911 has been published by P. Marshall.[14] He gives a list of the more important publications prior to 1911.[15] Examination of these publications and of a moderate number that have appeared since 1911 impresses the fact that except in New Caledonia almost no geological maps have been made of the islands in the Pacific designated as Oceania. There are some maps such as that of Mango in the Fiji group by Andrews[16] and sketch maps are included in some reports such as those by Elschner,[17] Friederici,[18] and Foye.[19] The amount of detailed geological information on Oceania is surprisingly small and one of the prime needs for the advancement of the geological knowledge of that part of the Pacific is more attention to accurate geological mapping.

I have not found references to geological maps of New Caledonia of a later date than those mentioned by P. Marshall in his summary of the geology of Oceania already mentioned, but it is my belief that maps have been published more recently.

GEOLOGICAL MAPPING IN THE EAST INDIES

The geological literature on the Dutch East Indies has been listed by Verbeek in the very helpful publication cited below[20].

[14] Marshall, P., Oceania: Handb. Regionalen Geologie, vol. 7, pt. 2, 36 pp., 1911.

[15] Op. cit., pp. 34-36.

[16] Andrews, E. C., Notes on the limestones and general geology of the Fiji Islands, with special reference to the Law group: Harvard Coll. Mus. Comp. Zool., vol. 38, 50 pp., 110 pls., 1900. See particularly plate I, a geological map of Mango.

[17] Elschner, Carl, Corallogene Phosphat-Inseln. Austral-Oceaniens und ihre Produkte, 118 pp., 14 pls., Max Schmidt, Lübeck, 1913. Contains maps of Nauru, Angaur, and Makatea, and a few sketches.

The Leeward Islands of the Hawaiian Group, 68 pp., Sunday Advertiser, Honolulu, 1915. Contains some rough sketches.

[18] Friederici, Georg, Ein Beitrag zur kenntniss der Tuamotu-Inseln: Leipzig Verein für Erdk., pp. 97-176, 4 pls., 1911. Contains 2 plates of sketch maps.

[19] Foye, Wilbur Garland, Geological observations in Fiji: Amer. Acad. Arts and Sci., vol. 54, pp. 1-145, 1 pl., 40 figs. in text, 1918. Contains sketch maps of southwestern Viti Levu, Navua delta-plain, Lambasa delta-plain, near Vanilangi (Vanua Levu), Taviuni, Vanua Mbalavu, Avca, Malatta and Susiu, Thikombia-i-lau, Tuvutha, Lakemba, and Ndelai Yaloi (Kambara).

[20] Verbeek, R. D. M., Opgave van geschriften over geologie en Mijnbouw van Nederlandsch Oost-Indië: Geolog.-Mijnbouwk. Genootsch. voor Nederl. en Kol. Verhandl., geol. ser., deel 1, blz. 31-248. Dec. 1912.

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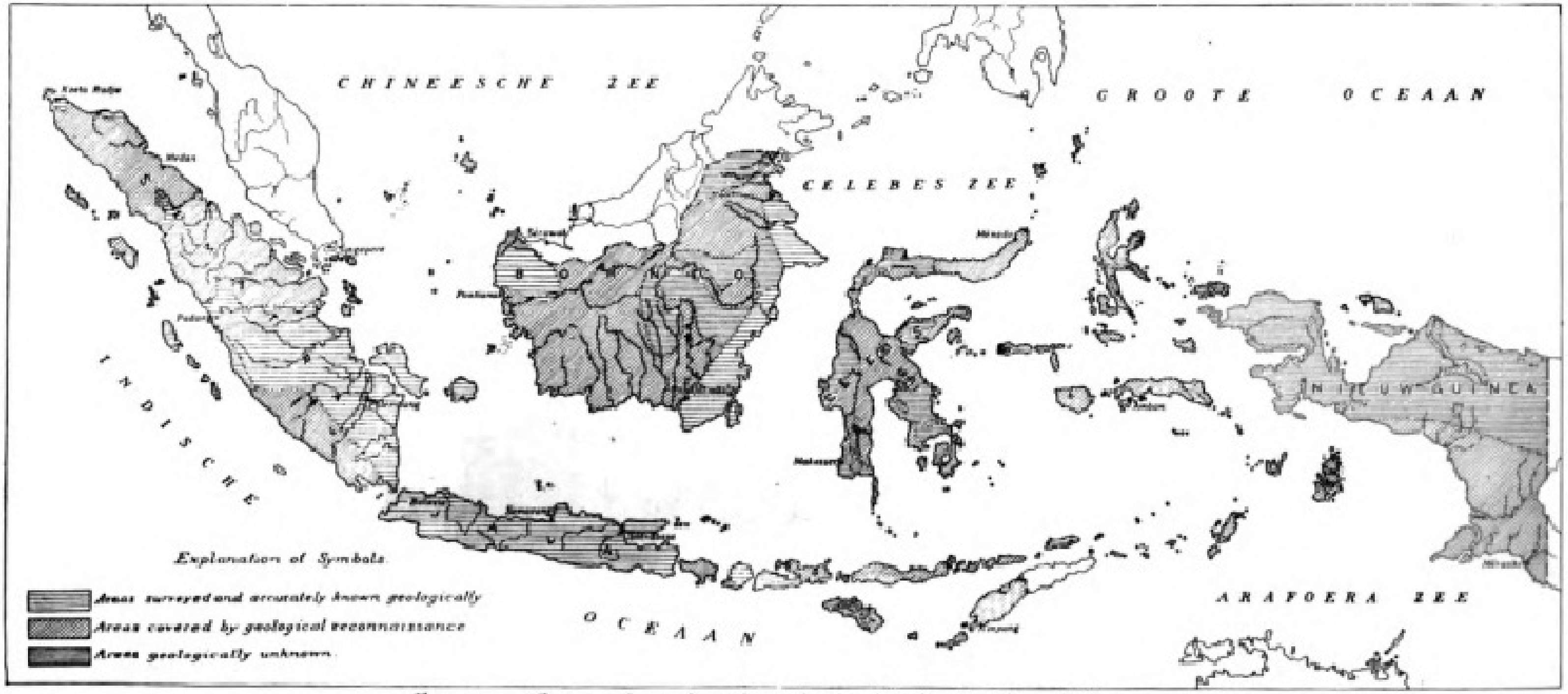


FIGURE 1. Status of areal geological mapping in the East Indies.

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which he has tried to keep up to date by the issue of supplements. The bibliographic references in this work are not exclusively confined to the Dutch East Indies as indicated by its title, for publications on British North Borneo, Portuguese Timor, British New Guinea, Siam, The Straits Settlements, and other outlying areas are also listed. This is an invaluable work for those who need to know the geological literature on the western tropical Pacific.

A key map showing the status of areal geological mapping in the Dutch East Indies is given by E. C. Abendanon on his Geologische Schetskaarte van Nederlandsch Oost-Indië,[21] scale 1:2,500,000, and it is here reproduced. An inspection of this map (figure 1) shows that although much geological work has been done in the East Indies, chiefly by the geologists of the Hoofdbureau van het Mijnwezen, large parts of vast areas are not at all or very imperfectly known. The extent of the larger East Indian islands is not grasped by many persons until they have had occasion to consider the matter. The area of Borneo is 286,000 square miles;[22] that of Sumatra, about 171,000 square miles; that of Java (including Madura) about 50,800 square miles; and that of New Guinea about 313,000 square miles. The area of France before the recent additions to its territory was estimated as about 204,000 square miles and the area of the State of Texas is about 265,800 square miles. Borneo and New Guinea are both larger than Texas; Sumatra is about 16 per cent smaller than France; and Java is about the size of England and one-quarter the size of France. The governments that have done so much in the study of the geological and other features of these islands deserve congratulation both on their policies and accomplishments. Some of the difficulties that beset geological interpretation in this part of the world are discussed in the articles on the correlation of post-Cretaceous geological formations. These difficulties in geological correlation express themselves in geological mapping.

A recent publication that deserves mention in this connection is H. A. Brouwer's Geologisch overzicht van het oostelijk gedeelte van den Oost-Indischen Archipel.[23] Pages 3-18 are

[21] Kon. Nederl. Aardrijksk. Genootsch., 1914.
[22] Areas taken from the Century Atlas.
[23] Jaarbk. van het Mijnwez. in N. O. I., 46 ste Jaarg. Verhand., 2 de deel., 308 pp., 1 Kaart in 4 blad. (Kaart II), 3 prof., 1 teeken., en 16 foto's, 1919. Jaarb. Mijnwez. Verhand. 46, deel 2, 1919.

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devoted to a partial bibliography of geological literature on the eastern East Indies. The work is divided into four parts as follows: (1) The sediments and eruptive rocks; (2) Summary of the historical geology: (3) Tectonics: (4) Volcanism and earthquakes.

Some of the more important geological maps of the East Indies are as follows:

Sumatra. R. D. M. Verbeek, K. A. Naumann, and J. F. de Corte, Geognostische Kaart van het Oembilien Kolenveld in de Padangsche Bovenlanden Sumatra's Westkust. Scale. 1:10,000. C. F. Stemler, Amsterdam, 1874. Accompanies Jaarb. Mijnwez. deel 2, 1875.

R. D. M. Verbeek, C. J. van Schelle, R. Fennema, and D. de Jongh H. Geologische Kaart van een gedeelte van het Gouvernement Sumatra's—Westkust in 7 Bladen, schaal 1:100,000. Uitgeg. C. F. Stemler, Amsterdam, 1883.

Java and Madoura. R. D. Verbeek en R. Fennema, Geologische Kaart van Java en Madoura in 26 bladen, schaal 1:200,000. J. G. Stemler Cz., Amsterdam, 1896.

Borneo. G. A. F. Molengraaff, Geological explorations in Central Borneo. Atlas in 22 sheets. Published by the Soc. for the promotion of the Scientif. Explor. of the Dutch Colonies. E. J. Brill, Leyden; H. Gerlings, Amsterdam, 1902. See also Theodor Posewitz, Borneo: Its geology and mineral resources, translated by F. H. Hatch, Edward Sanford, London, 1892. This work contains a geological sketch map of Borneo on a scale of 50 miles to 1 inch and a map, on the same scale, showing the distribution of useful minerals.

Célèbes. E. C. Abendanon, Voyages géologiques et géographiques à travers la Célèbes Centrale. Atlas. E. J. Brill. Leide, 1916.

Moluccas. R. D. M. Verbeek, Geologische schetskaart van het oostelijke gedeelte van den Nederlandsch-Indischen Archipel, schaal 1:3,000,000. In Atlas of Rapport sur les Moluques, reconnaissances géologiques dans la partie orientale de l'Archipel des Indes Orientales Néerlandaises. (Édition française du Jaarb. van het Mijnwez. Nederland. Oost-Ind., tom. 37, 1908.)

Amboina. R. D. M. Verbeek, Carte géologique de l'Ile d'Ambon, à l'échelle de 1:100,000; Carte géologique de Leitimor, en 5 feuilles avec titre, à l'échelle de 1:20,000; Carte géologique

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de la partie supérieure du Gounoung Nona, à l'échelle de 1:10,-000. In Atlas of Description géologique de l'Ile d'Ambon. (Édition française du Jaarb. van het Mijnwez. Nederland Oost. Ind., vol. 34, 1905.)

Timor. G. A. F. Molengraaff. The results of Professor Molengraaff's investigaitons in Timor are now being published by Hoofdbureau van het Mijnwezen and will constitute an important addition to the knowledge of the geology of the East Indies.

New Guinea. Such information as is available on the geological cartography of Dutch New Guinea is given on Abedanon's Schetskaarte, already mentioned, and the general geology of that part of New Guinea is summarized by Brouwer in his Geologisch Overzicht, also mentioned above. F. R. C. Reed, in his work cited below,[24] summarizes the geology of British New Guinea and that part of New Guinea formerly known as Kaiser Wilhelmsland. Knowledge of the old British part of the island is still largely confined to a reconnaissance made by Maitland[25] in 1891. The map in this report is on a scale of 10 miles to 1 inch and covers that part of New Guinea south of latitude 8° S. and east of longitude 146° 15′ E. On page 33 is a bibliography of the geology of New Guinea. Three more recent reports need mention. All are by Stanley[26] as noted below. The map of Woodlark Island is on a scale of about 2 1/3 miles to 1 inch and is colored; the maps in the report on petroleum in Papua are traverse maps on a scale of 2 miles to 1 inch of the country between Purari Delta and Yule Island. Some geological data are plotted on the maps. The other report, also by Stanley,[27] contains a general geological map of Misima Island on a scale of 1 mile to 1 inch, and two detailed maps of mining centers, one Mt. Sisa and Umuna, the other of Quartz Mountain, both on a scale of four chains (264 feet) to 1 inch. As New Guinea

[24] Reed, F. R. C., The geology of the British Empire, pp. 416-424, 1921.

[25] Maitland, A. Gibb., Geological Observations in British New Guinea in 1891: Queensland Geol. Survey, Parliamentary rept., 33 pp., geological sketch map, 1892. Published by Government Printer, Brisbane.

[26] Stanley, Evan R., Report on the geology of Woodlark Island: 23 pp., geol. map., Govt. publication, Melbourne, 1913. Stanley, Evan R. Report on petroleum in Papua: 48 pp., 2 maps, Publication of Commonwealth of Australia, Melbourne, 1914.

[27] Stanley, Evan R., Report on the geology of Misima (St. Aignau) Louisiade gold-field: Terr. of Papua Bull. No. 3, 25 pp., 3 geol. maps, 1915.

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is now attracting considerable attention, perhaps its geology will soon be rather well known.

MALAY PENINSULA

No systematic geological survey has been completed for the Malay Peninsula. Reed in his work already cited (pp. 325-333) gives a condensed sketch of the general geological features and references to the literature. The principal student of the geology of the region is J. B. Scrivenor, who since he became geologist of the Federated Malay States has done much to make the geology of that region known. The following are publications in which I have seen geological maps:

Jones, W. R., The origin of the secondary stanniferous deposits of the Kinta District, Perak (Federated Malay States): Geol. Soc. London Quart. Jour., vol. 72, pp. 165-197, pls. 13-15, 1917. Plate 15 is a black and white geological sketch map of the Kinta District, Perak; scale, 1:190,080.

Scrivenor, J. B., Note on the sedimentary rocks of Singapore: Geol. Mag., dec. 5, vol. 5, pp. 289-291, pl. 11, 1908. The plate is a rough sketch map of the Federated Malay States on which the main outcrop of the Tembeling series (Gondwana rocks) is shown.

Scrivenor, J. B., The geological history of the Malay Peninsula: Geol. Soc. London Quart. Jour., vol. 69, pp. 343-371, pl. 35 (map), 1913. The map accompanying this article is entitled "Sketch map of the Malay Peninsula showing diagrammatically the chief structural features;" scale, 1:3,041,280. This is probably the most important single article on the geology of the Malay Peninsula.

Scrivenor, J. B., and Jones, W. R., The geology of South Perak, North Selangor, and the Dindinas, with a geological sketch map: Geol. Dept. Fed. Malay States, 196 pp., 15 pls., 1919. The geological map is entitled "Geological sketch map of South Perak and North Selangor;" scale, four miles to one inch, about 1:350,000. The first four pages of this report are devoted to an account of previous literature. Verbeek gives a bibliography in his work, already mentioned, on the geological literature on the Dutch East Indies.

Willbourn, E. S., The Pekang volcanic series: Geol. Mag., dec. 6, vol. 4, pp. 503-514, pl. 30 (map), 1917. The map (plate XXX) is entitled "Geological sketch map of part of

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Ulu Pahang." It is black and white and on a scale of about 12 miles to 1 inch.

FRENCH INDO-CHINA

The principal publications on the geology of French Indo-China are those of the Service géologique de l'Indochine. The latest of the publications of this institution received at the library of the United States Geological Survey are dated 1919. Three of the available reports contain geological maps. They are as follows:

Deprat, J., and Mansuy, H., Étude géologique du Yunnan Oriental, ière partie, Géologie generale: Service géol. de l'Indochine, mém., vol. 1, fasc. 1, pp. 370, 20 pls., and maps. The general title of the maps is "Carte géologique du Yunnan, Oriental," scale 1:200,000. There are three "feuilles," each composed of two sheets making six sheets. Feuille 1 is entitled Tong-Chouan; 2, Yunnan-Fou; 3, Mong-Tseu. The area covered by these maps lies between latitude 23° 15″ and 26° 30′ N., and longitude 102° and 104° E.

Deprat, J., Études géologiques sur la région septentrionales du Haut-Tonkin (feuilles de Pa-Kha E., Ha-Giang, Ma-li-Po, Yen-Minh): Ibid., mém., vol. 4, fasc. 4, 175 pp., 39 pls., sheets of sections and maps, 1915. The maps in this volume are on a scale of 1:100,000. The areas covered by them are northeast of Hanoi.

Giraud, J., Notes géologiques sur la partié nord-est du Tonkin (feuilles de That-Khe, Pho-bink-gia, Lang-son): Ibid., bull., vol. 5, fasc. 1, 66 pp., geological sketch map on scale of 1:500,000, 1918. The geological studies in this area which is about 100 kms. from north to south and about 150 kms. from east to west have not been completed.

It is very probable that more work has been done in French Indo-China than I am acquainted with at present. However that may be, the geologists of the Service géologique de l'Indo-China have been making praiseworthy progress in their mapping of the geology of that region and it is reasonable to hope that before many years they will publish a reliable general geological map of it.

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AREAL GEOLOGICAL MAPPING IN NEW ZEALAND

By P. G. Morgan, Director of the New Zealand Geological Survey, Wellington, New Zealand

The first noteworthy geological maps of any portion of New Zealand were those prepared by F. von Hochstetter and Julius von Haast over 60 years ago. One of these maps, representing the geology of the provincial district of Nelson, the northwestern part of South Island, was published in 1861 with von Haast's Report of a Topographical and Geological Exploration of the Western Districts of the Nelson Province. Hochstetter and Peterman's Geological and Topographical Atlas of New Zealand,[1] published soon afterward, contains a small-scale map of part of Auckland Province, and larger scale maps of Auckland Isthmus, of the Kawhia-Raglan district, and of the neighborhood of Lake Rotomahana, together with the above-mentioned map of the Nelson Province.

Soon after Hochstetter's visit to New Zealand, several of the Provincial governments,[2] which at that time had considerable power independent of the main Government and Legislature, instituted geological surveys. The early Provincial geologists were Mr. J. C. Crawford, Wellington; Dr. Julius von Haast, Canterbury; and Dr. James Hector, Otago. Mr. A. D. Tripbook possibly held a similar position in Hawke's Bay, but no official record of his work has been found by the writer. During the "seventies" Captain F. W. Hutton was Provincial Geologist in Otago for two or three years. The only notable maps published by the provincial geologists were Hutton's map of Otago (1875) and von Haast's map of Canterbury and Westland (1879). Both are on a very small scale.

Much of the work done by the provincial surveys was incorporated on maps published by the Geological Survey of New Zealand, which began its existence in 1865 with Dr. (Sir) James Hector as Director. In 1869 and again in 1873, Hector published sketch geological maps of New Zealand on scales which, as measured on actual examples of the maps, were approximately 1:2,319,000 and 1:2,015,000, or 36.6 and 31.8 miles respectively

[1] German edition, Gotha, 1863; New Zealand edition, Auckland, 1864. See also report of Novara expedition, geology.

[2] The provincial governments and with them the "provinces" were abolished in 1877. Though they no longer represent political divisions, the names are still commonly used.

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to the inch. The 1873 map professes to be on the scale of 1:2,000,000, erroneously stated to be equivalent to 33.31 miles to the inch.

In 1884 and again in 1886, Hector published a geological map of New Zealand on a still smaller scale than those of 1869 and 1873. The small-scale maps published by Professor James Park in 1910, and Dr. P. Marshall in 1912 should also be mentioned.

During the period of 1865 to 1894, the Geological Survey published with the reports of its various officers a great number of sketch maps varying in scale, detail and quality. In those days few topographical maps even of moderately good quality were available, much of the country was covered by forest, and present-day roads and railways were mostly unmade or still in the making. Hence Hector and his staff worked under great difficulties, and as a rule did not attempt to produce highly detailed geological maps. Some creditable manuscript maps were spoiled by being published on too small a scale. Worthy of mention, however, are some excellent topographical maps of the Buller Coalfield, showing coal outcrops, which were published in 1877. These were drawn by A. Koch from surveys made by W. M. Cooper.

In 1893 and various succeeding years geological maps of various parts of New Zealand, prepared by Alex. McKay to illustrate his reports, were published by the Mines Department. Nearly all of these maps are on a small scale, and very sketchy in detail, but have nevertheless been useful to students of New Zealand geology. In 1897 both McKay and Park published geological maps of the Hauraki Gold Field (Auckland) which are useful in illustrating the views of the two geologists, but neither map can lay claim to any great decree of accuracy.

Besides the maps already mentioned, many small geological maps of portions of New Zealand have been published in connection with papers on the geology of this country. Some of these will be found in the Transactions of the New Zealand Institute.

So far as reconnaissance surveys are concerned, one may say that the whole of New Zealand is covered by the various maps already referred to. Some area has been repeatedly mapped, but without any great gain in general knowledge. The wasting of energy in this way is to be deplored, but, as a rule,

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where one perfunctory examination succeeds another, it is not the fault of the geologist but of circumstances beyond his control. Not until 1905, when Dr. J. M. Bell was appointed Director of the Geological Survey in succession to Sir James Hector, were systematic surveys instituted with a view of producing detailed geological maps of all New Zealand. Dr. Bell in 1906 stated his plan as follows:

> The reorganized Geological Survey Department has outlined a scheme for the preparation of a detailed topographical and geological map of New Zealand. For this purpose the country has been cut up into divisions, each one of which is supposed to present a problem of special interest, or several such problems, which can be conveniently grouped together. For example the Hauraki division is of note chiefly on account of its containing the richest quartz-mining fields of the colony; the Karamea division contains the immense iron-ore deposits occurring near Parapara; the Westland division is of marked interest because of its richly auriferous gravels, and of the veins and rock masses from which they were derived; the Rotorua division contains the chief manifestations of the remarkable thermal phenomena for which New Zealand is justly famed, and so on.
>
> Each division contains a number of survey districts corresponding in boundary with those of the Lands and Survey Department. Several survey districts which can be conveniently grouped together to give a continuous section of country comprise a sub-division. It is intended to prepare full reports, accompanied by geological and topographical maps, on each subdivision as soon as the necessary field-work in each case is completed, and to issue them to the public without delay at an almost nominal price.
>
> In carrying out the field-work a good topographical map is the first requisite, and on it as a basis, the geological work is placed. The whole area which is being investigated is most carefully examined, the various creeks are ascended, and the spurs and ridges followed in mountainous country. Every phase of geological science is given attention—the paleontologic, petrographic, structural, physiographic and economic. However, especial stress is laid upon the economic side of geology, which relates to the occurrence of minerals of commercial value, and has a direct bearing upon the mining industry, the development of which is so important in any new country.

It may be noted that a manuscript map still in existence shows that Sir James Hector in the early years of his directorate planned to make a complete geological survey of New Zealand on a basis similar to that outlined by Dr. Bell. The difficulties already mentioned and other circumstances prevented the scheme from being carried out to any great extent, though the Buller Coalfield survey was evidently executed in accordance with it.

The scheme of geological survey instituted by Dr. Bell has been followed to the present time, and a number of bulletins accompanied by areal maps on the scale of one inch to the mile (1:63,360) have been published. In one case (Tuapeka District,

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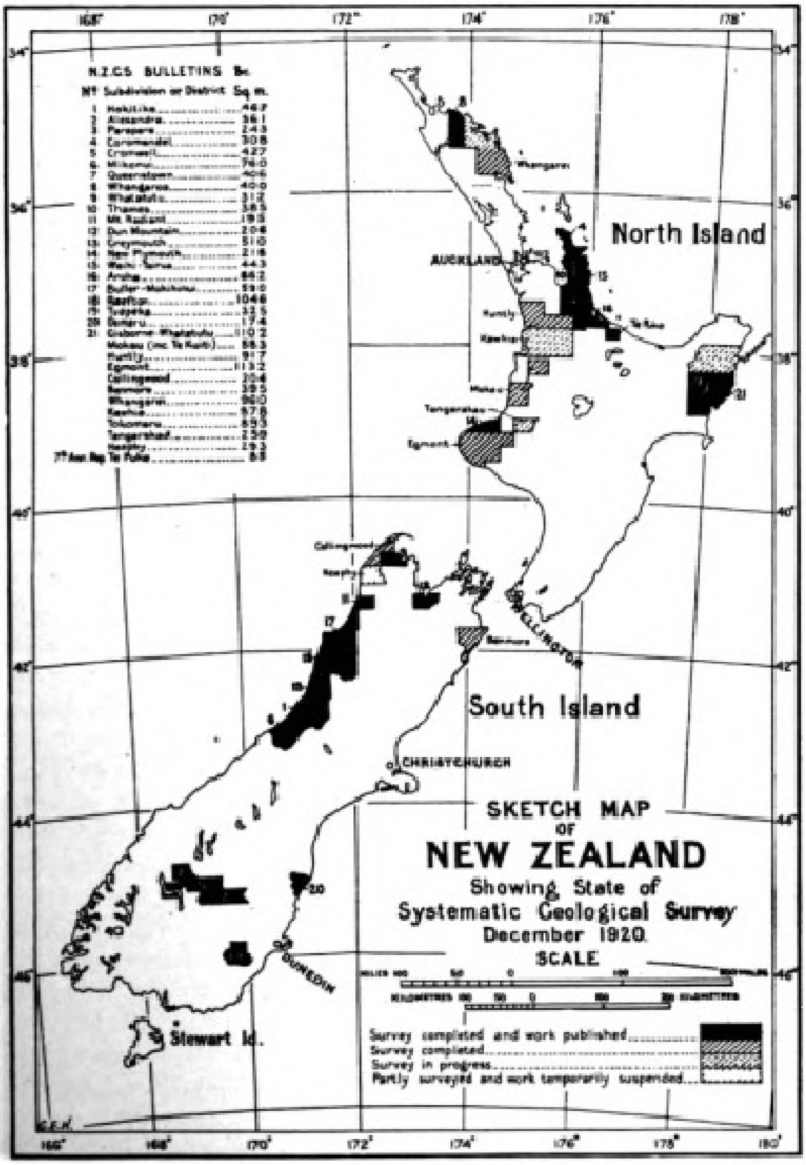


FIGURE 1. Map of New Zealand showing status of geological surveys.

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Bulletin No. 19) the geological map is on the scale of two inches to the mile (1:126,720). Besides the geological maps many topographical maps, usually on the 1:63,360 scale, together with various large-scale maps of special mineral areas, have been issued. The present state of the survey may be summarized as follows:

	sq. mi.	sq. km.
Areas in which survey is completed and work published on the 1:63360 scale	8983	23264.6
Area in which survey is completed and work published on the 1:126720 scale	325	841.7
Areas in which survey is completed, but work is not yet published	3711	9610.9
Areas in which survey is in progress	2510	6500.5
Area (Heaphy) in which work is suspended	293	758.8
Total	15822	40976.5
Area resurveyed (Whatatutu)	312.5	809.3

The sketch map (figure 1) shows the areas in which detailed surveys have been made or are now being carried on. All work has been done with a view to publication on the one inch to the mile (1:63,360) scale, except in the Tuapeka District and in part of the Egmont District.

In addition to the areas shown on the map part of Southland (south part of South Island) has lately been geologically examined by Professor James Park for the Mines Department. A portion of this area, the Nightcaps—Mt. Linton Coalfield, was surveyed by him in some detail.

According to the official Year Book, 1919, the total area of New Zealand, excluding the Cook and other islands annexed in 1901, is 103,581 square miles, equal to 268,258.7 square kilometers. Hence somewhat over one-seventh of the Dominion has been or is being geologically surveyed in detail. Much more than one-seventh of the work required to make a complete geological map answering the requirements of the present day has been done because of the foundation afforded by the early reconnaissance surveys, and the fact that most of the country remaining to be surveyed is less difficult than the average of that already mapped. In order, however, that this statement may remain true, the present survey must be completed during the present generation; otherwise the progress of geological science will render the work already accomplished partly obsolete before the detailed survey now in hand has reached every part of the country.

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GEOLOGICAL MAPPING IN AUSTRALIA[1]

INTRODUCTION

By T. Wayland Vaughan

The following statements regarding the present status of geological mapping in Australia will be introduced by references to geological maps and general accounts of the geology of the entire continent and to treatises on the geology of the different states.

Two official geological maps of all of Australia appear to have been published but I have found copies of only one of them, the earlier one, in Washington. The following is a record of these maps.

R. Brough Smyth, First sketch of a Geological Map of Australia including Tasmania: scale, 1:7,000,000: Published by direction of the Minister of Mines for Victoria, 1st Nov., 1875. The date of the preparation of the map is given as 25th April, 1873. The other map is listed in the circular of the Office of Mines, Melbourne, May, 1920, entitled "Maps, Plans, and Reports," as "Australia (6 sheets), 1887."

J. W. Gregory in his work cited below[2] gives a brief description of the geological features of each state under the description of the state. Facing page 104 of this work is a geological map of Australia on a scale of 1:14,256,000.

Another general account of the geology of Australia is that by David,[3] and the same author's paper on the tectonic features of Australia[4] is also worthy of special attention, as it gives a good summary of information on that important subject. A third summary of the geology of Australia is given by Reed.[5]

[1] The material included under this heading has been assembled under the direction of the leader of the Section of Geology, T. Wayland Vaughan, and the text has been in large part prepared by him.—*Committee on Publication.*

[2] Gregory, J. W., Australasia, vol. 1, Australia and New Zealand: Stanford's compendium of geography and travel (new issue). 657 pp., maps and diagrams unnumbered, 80 unnumbered illustrations. London, Edward Stanford, 1907.

[3] David, T. W. E., Geology of the Commonwealth: Federal Handbook for the Australian Meeting of the Brit. Assoc. Adv. Sc., 9 pls., 6 figs., geological map and orographical map in colors, pp. 241-325, 1914.

[4] David, T. W. E., Notes on some of the chief tectonic lines of Australia: Roy. Soc. N. S. W., vol. 45, pp. 4-60, 1911.

[5] Reed, F. R. C., Geology of the British Empire, pp. 349-395, 2 maps, 1921. Map of New South Wales, scale about 100 miles to 1 inch; geological sketch map of Australia, scale about 300 miles to 0.97 inch.

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An old but valuable work on the geology of Tasmania is that of Johnston.[6] For the results of later work the publication of the Geological Survey of Tasmania especially should be consulted. There is no late publication summarizing geological information on Victoria. No single volume appears to have taken the place of Murray's work.[7] For South Australia, Howchin has given a revised summary up to 1918;[8] and Gibb Maitland has just published a summary to date of the geology of Western Australia.[9] Süssmilch[10] has published a useful and convenient volume on the geology of New South Wales; and Etheridge and Jack[11] are the authors of a work on Queensland. Notwithstanding later publications these two volumes by Jack and Etheridge must continue to rank among the classics of Australian geologic literature. Geologists are indebted to Woolnough for a summary statement of the geological features of the Northern Territory.[12]

This brief review of the literature shows that the geological features of Australia have been very well summarized and those interested in the subject can get a good grasp of the present knowledge of that continent by reading relatively few volumes. The Australian geologists deserve congratulations on the way in which they have presented the results of their investigations.

[6] Johnston, R. M., Systematic account of the geology of Tasmania: pp. vi-408, pls. 1-23, i-iii, I to LVII. Published by authority of the Government, Tasmania, 1888. Contains a geological sketch map on a scale of 15 miles to 1 inch; this map follows p. 408 and bears no plate number.

[7] Murray, R. A. F., Victoria, geology and physical geography: 150 pp., colored geological map, 48 figs. Published for and on behalf of the Government, Melbourne, 1895.

[8] Howchin, Walter, The geology of South Australia: pp. vi-543, 330 figs., geol. map in black and white. Published by the Education Dept., Adelaide, 1918.

[9] Maitland, A. Gibb, A summary of the geology of Western Australia: Western Australia Geol. Survey mem. 1, Mining Handb., chap. I, 55 pp., 1920. Contains geological map, revised to 1920, scale 50 mi. to 1 in.

[10] Süssmilch, C. A., An introduction to the geology of New South Wales, 269 pp., 92 figs., 1 colored geological map; Angus and Robertson Ltd., Sydney, 1914.

[11] Etheridge, R. Jr., and Jack, R. L., Geology and paleontology of Queensland, 1 vol. text, pp. xxx+768, 1 vol. of 66 plates. Published under the authority of the Minister of Mines and Public Instruction, Brisbane, 1892.

[12] Woolnough, W. G., Report on the geology of the Northern Territory: Northern Territory Bull. 4, 11 pls., geol. map on scale of 20 mi. to 1 in., 6 text figs. Published by Dept. of External Affairs, Melbourne, 1912.

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Geological maps of the different Australian States have been made on a scale of approximately 1:1,000,000, for all the States except Western Australia and the Northern Territory.

GEOLOGICAL MAPPING IN QUEENSLAND

By NELL BOWEN, Clerk of Section of Coastal Plain Investigations, United States Geological Survey

A list of the official geological maps of Queensland[13] shows that a great deal of attention has been paid to geological mapping in Queensland and that a map of the entire State on a scale of 16 miles to one inch, about 1:1,000,000, has passed through two editions. In the publications of the Geological Survey, maps, plans and sketches are freely used. Dr. Vaughan considers the Queensland Mineral Index, Publication 241 (36 maps), "the most complete record that I know of the mineral resources of any large region."

GEOLOGICAL MAPS OF THE ENTIRE STATE OF QUEENSLAND, ISSUED BY THE QUEENSLAND GEOLOGICAL SURVEY

1886, by R. L. Jack. Scale: 32 statute miles to 1 inch.
1888, by R. L. Jack, Scale: About 60 miles to 1 inch.
1892, by R. L. Jack and R. Etheridge, jr., Scale: 16 miles to 1 inch.
1899, by R. L. Jack. Scale: 16 statute miles to 1 inch.
1902, by H. W. Fox. (Sketch map). Scale: 40 miles to 1 inch.
1905, by H. W. Fox. (Showing mineral localities). Scale: 40 miles to 1 inch.
1908, by H. W. Fox. (Showing mineral localities). Scale: 40 miles to 1 inch.
1913, by B. Dunstan, 2 maps: map showing districts, railways, and geological features. Scale: 120 miles to 1 inch; map showing areas of mineral production. Scale: 120 miles to 1 inch.

GEOLOGICAL MAPPING IN NEW SOUTH WALES

By E. C. ANDREWS, Government Geologist

The map (fig. 1) shows the present status of areal geological mapping in New South Wales. The Department of Mines of New South Wales published in 1914 a geological map of the state, scale 16 miles to one inch, prepared under the direction of E. F. Pittman, Government Geologist.

[13] The manuscript submitted by Miss Bowen lists upwards of 330 maps, plans, profiles and geological sketches for which full information is given. The limitations of space have made it impracticable to publish more than the list given below. Further information may be obtained from the Government Geologist, Queensland, or from H. C. Richards, Professor of Geology, University of Queensland.—*Committee on Publication.*

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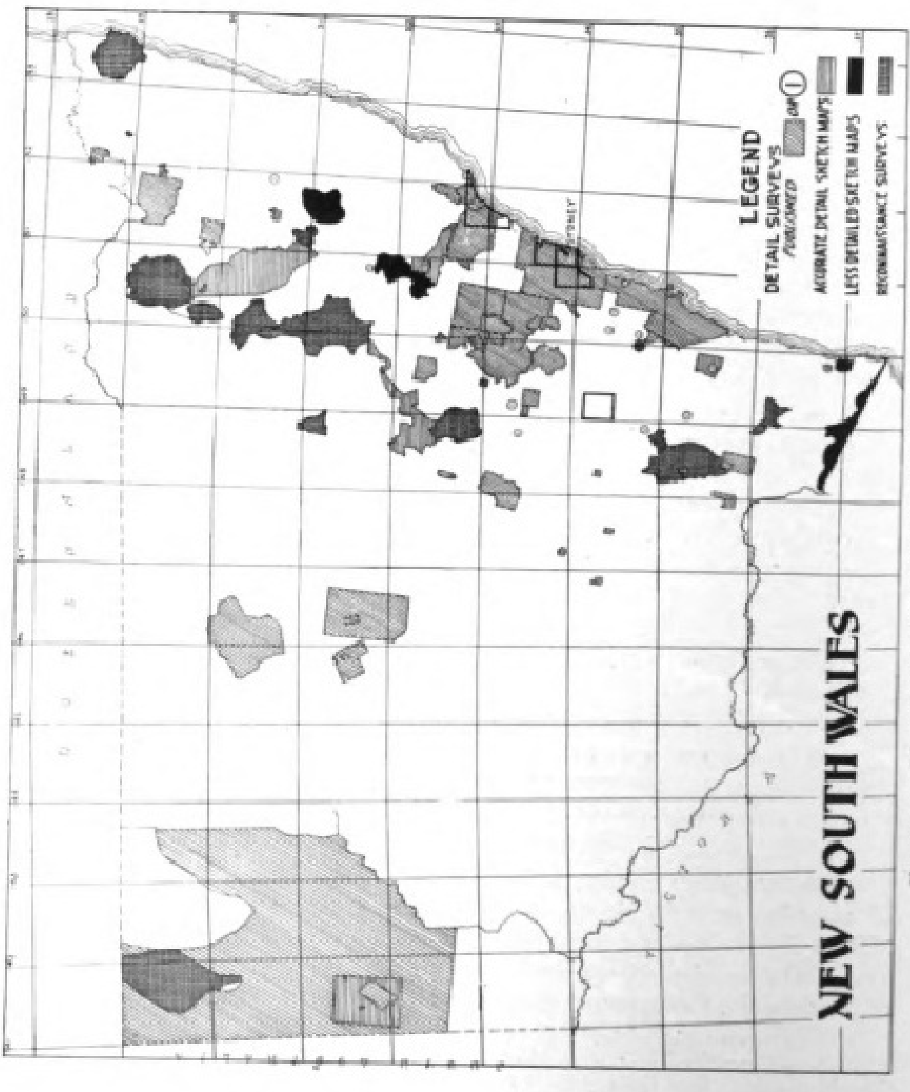


FIGURE 1. Map showing extent and character of geological mapping in New South Wales. The areas in solid black lines have been contoured at intervals of 50 feet.

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GEOLOGICAL MAPPING IN VICTORIA

BY W. BARAGWANATH, Director of the Geological Survey of Victoria

The present status of geological surveys in Victoria is indicated on the map reproduced in figure 2 of this article. Geological maps of the entire State have been issued as follows:

Geological map, 2 sheets, 1872;

Geological map, 1 sheet, scale 16 miles to 1 inch, 1909;

Mineral map, 1 sheet, scale 16 miles to 1 inch, 1909;

Auriferous map, 1 sheet, scale 16 miles to 1 inch, 1909;

A list of maps, plans, and reports may be obtained by application to the Office of Mines, Melbourne.

The Victorian quarter sheets (old series), the areal unit adopted by Selwyn, embraced an area of 9 miles by 6 miles and were laid out on magnetic meridian; a later series was laid out on true meridian and embraced 10′ Long. by 6′ Lat.

In Professor J. W. Gregory's directorship, 1900-1905, the State was divided to contain 400 sheets each of about 300 square miles; five sheets this size were made on a 40 chain scale.

The present practice is to adopt the Lands Department's parish plans and add geological and topographical features.

I might state that the State was triangulated in part prior to 1870, when the work ceased. Certain meridians were marked on the ground and formed the basis for the Lands Department surveys into parish plans of roughly 100 square miles area. The parish plans as issued by the Lands Department form the basis on which geological and topographical data are now added.

The present method of survey comprises compass traverses with steel tape measurements tied on to theodolite base work of the Lands Department.

The rapid contour surveys are by aneroid and cyclometer measurement recorded on a bicycle wheel.

The detail contour surveys are by tachometer and dumpy level.

The military maps are based on the primary triangulation, a secondary triangulation, and plane table and stadia work.

The datum for level is that adopted by the Victorian Railways.

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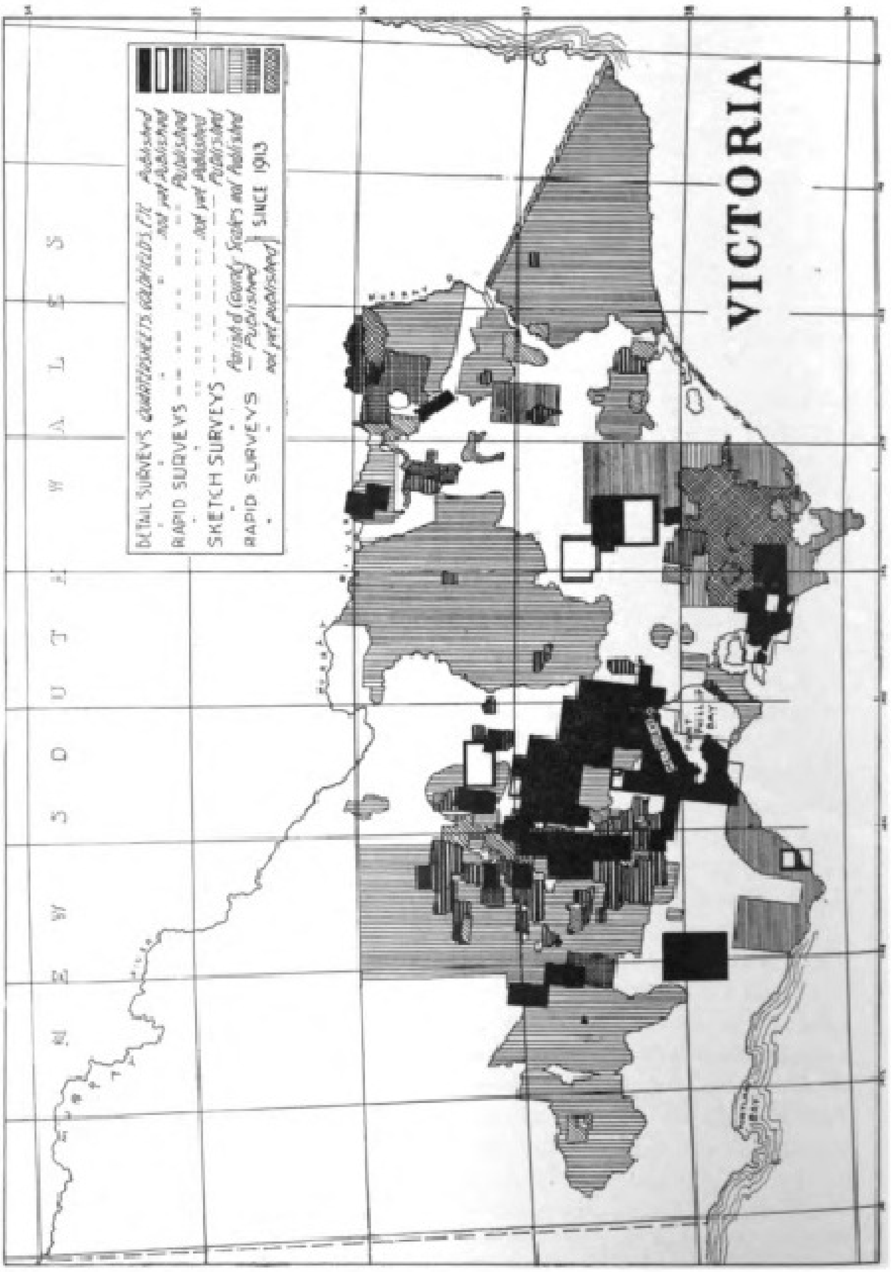


FIGURE 2. Map of Victoria showing status of geological surveys.

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GEOLOGICAL MAPPING IN TASMANIA

By LOFTUS HILLS, Government Geologist of Tasmania

Topography. There has been no attempt up to date to produce anything approaching a detailed topographic map of Tasmania. This work is not a function of the Geological Survey in Tasmania, but comes within the province of the Department of Lands. It may be mentioned that the trigonometrical survey of the island started many years ago has never been completed and no work thereon has been attempted for many years past. The most comprehensive map yet published is one on a scale of 8 miles to 1 inch, issued by the Surveyor General's office at Hobart. It is well known to contain a great number of errors. Even the coast line is not correct, especially in the southwestern portion.

The only attempt at a relief map of Tasmania so far made is that contained on page 176 of the "Australian Environment" by Griffith Taylor, which is a generalization of the main topographic features, but it has several obvious errors.

The completion of the trigonometrical survey of Tasmania and the initiation of a systematic topographic survey are highly desirable but at present are not seriously contemplated.

Geological Survey of Tasmania. The Geological Survey of Tasmania is a branch of the Mines Department. The Government Geologist is in charge and at present is assisted by three assistant government geologists, a chemist, a laboratory assistant and a clerk and typist. There is no provisoin on the staff for either a topographer or a paleontologist, and no special officer is provided for petrographical work.

The attention of the Geological Survey is mostly confined to the examination of metalliferous and coal mining fields. The areal geological mapping accomplished is incidental to these investigations, and the boundaries of the areas mapped are mainly determined by the extent of mining operations. Recently a considerable area in the Midlands has been geologically mapped in connection with the investigations of underground water supplies.

It has not been possible, in view of the continuous demands for investigations of mining fields, to divide the State into areas, the geological mapping of which could be systematically proceeded with. In fact during the last thirty years the same area has been repeatedly examined, each examination showing

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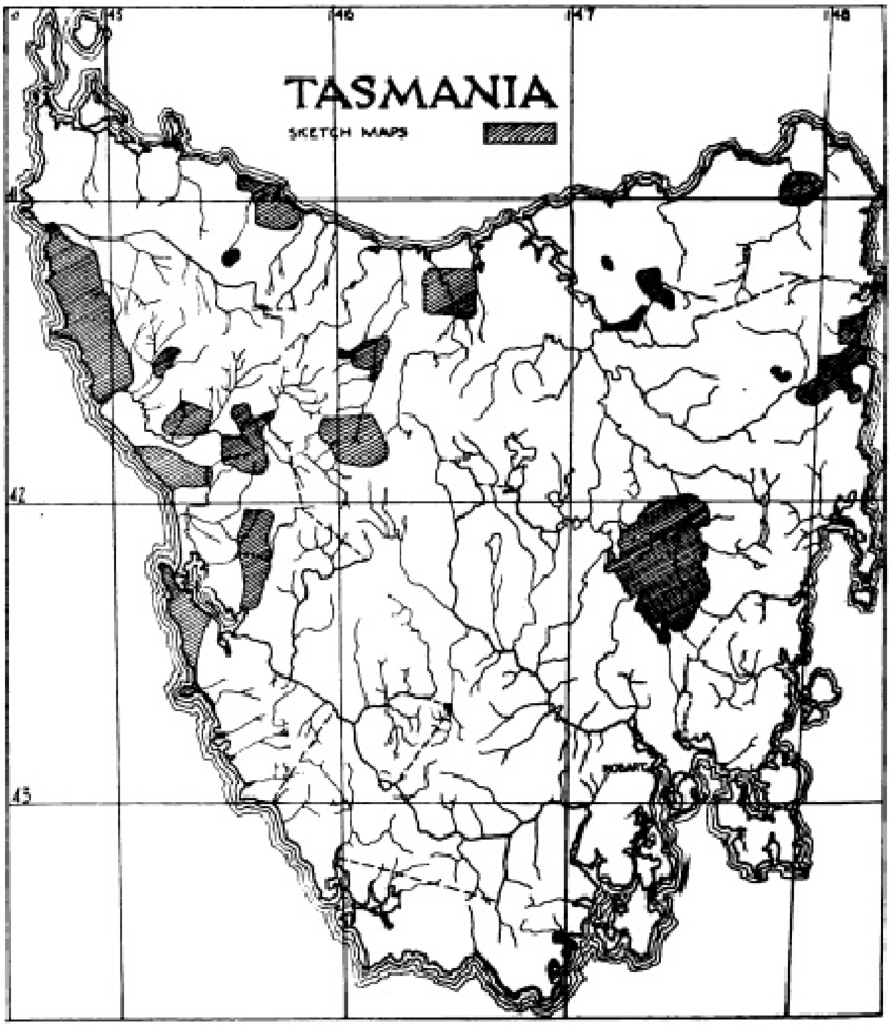


FIGURE 3. Map of Tasmania showing area covered by geological maps.

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more detail than the previous one. The practice adopted is that of making as complete an examination as possible in a certain specified time rather than the practice of making a complete and accurate geological survey of the area irrespective of the time required. The total area for which such geological maps have been prepared is 2,122 square miles. The total area of Tasmania is 26,215 square miles, so that the total area covered by the areal geological maps is nine per cent of the whole. The accompanying map (fig. 3) shows the position of those areas for which geological maps have been prepared.

There has been no standard scale of reproduction adopted. The originals are drawn to a scale of 20 chains to the inch, or 1 to 15,840, and the amount of reduction in printing has varied widely so that the final printed maps vary in scale from 1:133,000 to 1:5,140.

In regard to the quality of the maps it must first be stated that they cannot be regarded as accurate geological maps but are merely geological sketch maps. The geological boundaries are sometimes accurately surveyed, but are generally approximate only. The topography, as far as it is indicated by the position of streams and hachures, is partly surveyed and partly sketched in by the geologist. It should be here pointed out that the irregular topography, the dense and generally impenetrable forest growth, combined with the very wet climate make areal geological mapping in Tasmania very difficult especially on the West Coast.

In regard to the manner of reproduction of these maps it should be pointed out that the antiquated appliances available to the Government Printer do not permit of very satisfactory results especially in regard to the registering of colors.

Geological Map of Tasmania. As indicated by its title, Geological Sketch Map of Tasmania, this is merely a sketch map. It is on the scale of 15 miles to the inch, or 1 to 950,400. The smallness of the scale made it impossible to include much of the detailed information in regard to stratigraphy contained in the areal geological maps, for example, the West Coast Range Conglomerate now regarded as Silurian is not separated from the Cambro-Ordovician system, and in this latter system the sedimentary series are not separated from the Porphyroid Igneous Complex. Similarly there is no separation of the Permo-Carboniferous system from the Trias-Jura system. The preparation

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of a geological map of Tasmania on a larger scale than this is contemplated.

Mineral Map. A map of Tasmania which summarizes our present knowledge of the occurrence of economic minerals and the distribution of mineral fields is in preparation. [This map was exhibited at the Conference.]

Conclusion. It must be remembered in connection with this summary of the status of the Geological Survey of Tasmania that in spite of the absence of complete topographic maps and the fact that some portions of our areal geologic maps are admittedly approximate only, yet a vast amount of very valuable research has been carried out by the Survey in regard to the ore deposits of the State. This is the work for which the Geological Survey is specially organized, and the areal mapping has only come about as incidental to this, although it is now recognized by the Government that the ultimate completion of the geological survey of the island is very desirable. One of the great difficulties in the way of the ultimate completion of such geological survey of Tasmania is the non-provision of facilities for a topographic survey. Another difficulty which is very likely to arise is that of the areal geologic mapping of those portions of Tasmania which contain no geologic materials of economic value, for unless it is specially provided for, the attention of the Geological Survey to such areas is likely to meet with opposition from certain quarters.

GEOLOGICAL SURVEYS IN SOUTH AUSTRALIA

By L. KEITH WARD, Government Geologist of South Australia

The present status of areal geological surveying in South Australia is shown on figure 4. General geological maps of the State have been issued as follows:

4 sheets map, scale 16 miles to 1 inch (about 1:1,000,000), by H. Y. L. Brown, 1899.

1 sheet map, scale about 47.5 miles to 1 inch, based mainly on geological maps by H. Y. L. Brown.

1 sheet map, black and white, scale about 125 miles to 1 inch.

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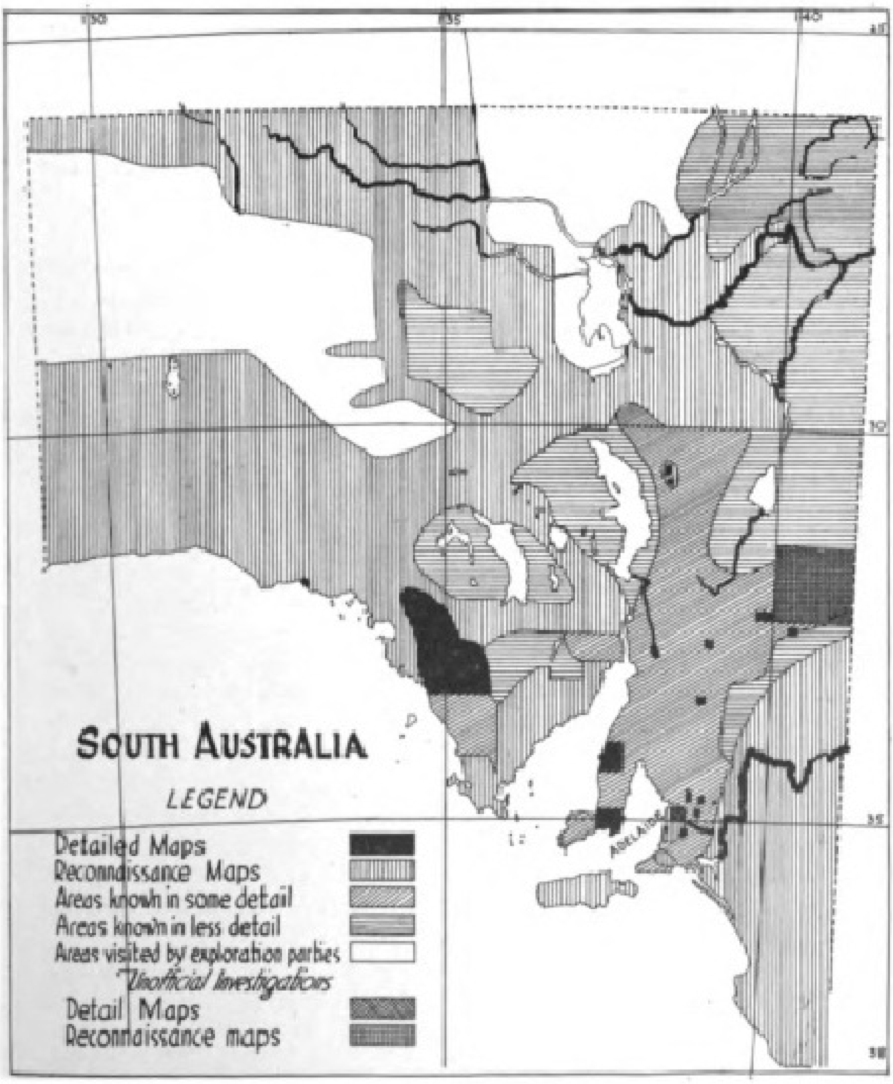


FIGURE 4. Map of South Australia showing area covered by geological maps.

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GEOLOGICAL SURVEY OF WESTERN AUSTRALIA

By A. GIBB MAITLAND, Government Geologist

In the year 1885, a motion was brought before the Legislative Council, having for its object "the establishment of a permanent geological department for the Colony," and about ten years later the paramount necessity for "the publication of reliable geological knowledge relating to the nature and extent of useful mineral deposits, supplemented by geological maps and plans" was impressed upon the Government of the day by its scientific advisers.

The work of organizing a more or less systematic geological survey was commenced in 1896, its object being the investigation of the geological structure, mineral resources, mining industries, and underground water supplies of Western Australia. These objects so far as available resources would permit, have been carried out by means of:

(a) Reconnaissance surveys of little known portions of the state; (b) detailed geological surveys of mining centers; (c) chemical and mineralogical examinations of soils, rocks, minerals and natural waters; (d) paleontological and petrological investigations; (e) the maintenance of a geological museum; and (f) the publication of maps and reports.

When viewed broadly, it may be said that the time of the staff of the Geological Survey has been pretty well divided between work in connection with (a) mining, (b) agriculture, (c) underground-water supply, (d) general geological surveys, (e) engineering questions, (f) chemical and physical research, and (g) petrological and paleontological investigations. The Geological Survey has therefore been *inter alia,* engaged upon the delimitation of the actual and potential mineral and underground-water resources of Western Australia, or in other words, "taking stock" of its mineral and allied resources and directing its energies to the investigation of those raw materials, the exploitation of which are of special importance under present conditions. The work of the different field parties has been primarily planned with the view to the determination of (a) the areal distribution, (b) the mode of occurrence, (c) the geological relationships, (d) the value of the mineral resources of the districts dealt with, and (e) the study of the structural features of the formations in which they are contained. The results of

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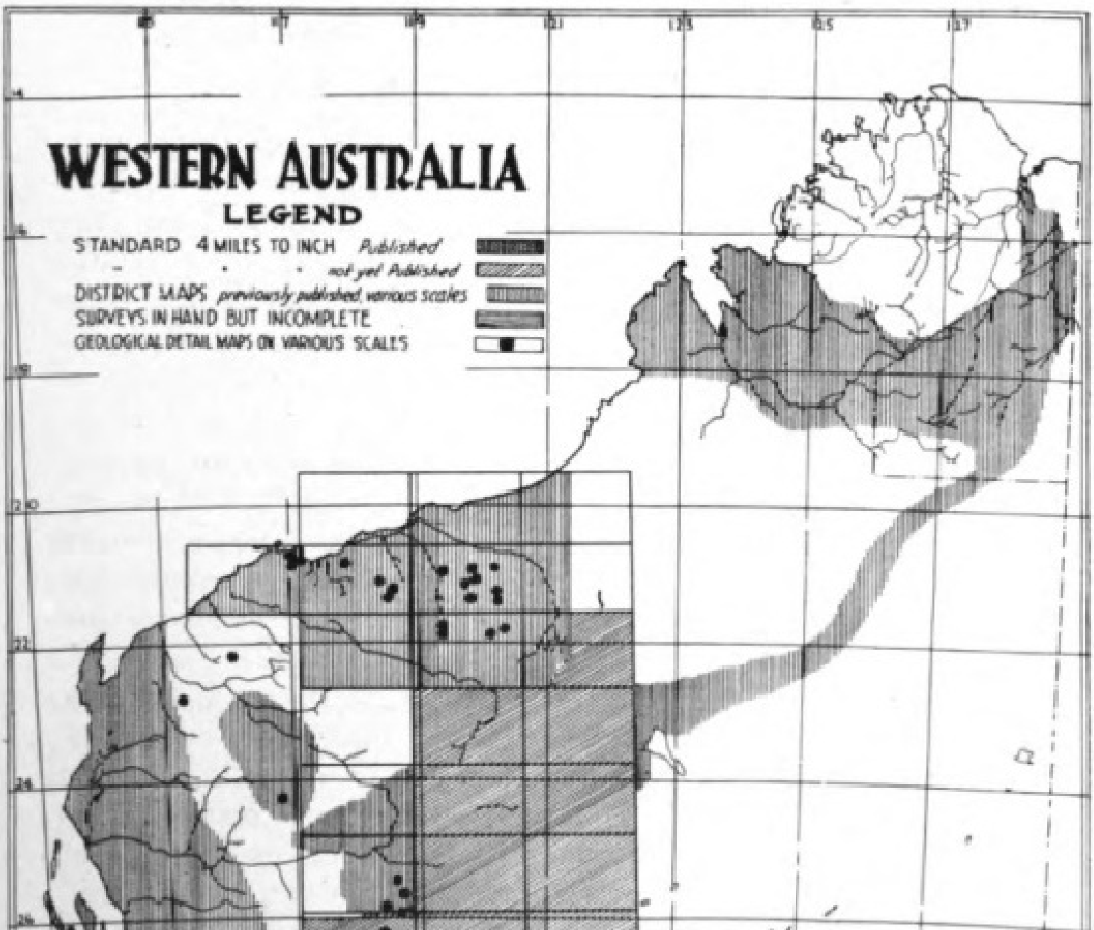


FIGURE 5. Map of Western Australia showing area covered by geological maps.

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these investigations have been made available to the general public in four distinct forms: annual reports, bulletins, memoirs, and maps (see fig. 5).

One of the most essential portions of the equipment of the Department is the Geological Museum, in which the various rocks, minerals and fossils collected by the staff in the ordinary course of its duties, or acquired by purchase or donation are exhibited and arranged for the benefit and instruction of the public in illustration of the geological reports and maps. The guiding principle in the arrangement of the exhibits is the illustration of the geological structure and mineral resources of the State, in addition to the application of geology to various industrial pursuits, and the more systematic treatment of the science of geology in general.

An exhibit of this kind will fairly and efficiently represent the mineral resources of the State, by giving undue prominence to no one mineral product, and neglecting nothing that is essential. The value of such a geological exhibit to the State will depend solely upon the exactness with which it reproduces the actual state of knowledge relating to the mineral resources of Western Australia, for any exaggeration in one direction or omission in another tends to leave an erroneous conception of the country's resources. By arranging exhibits in such a manner as to give the different mineral products prominence in accordance with their present or prospective importance, many valuable materials which are undeveloped would be brought under the notice of specialists and others, and in consequence would tend to receive quicker development than if they had not been placed on public view especially at a time such as this, when efforts are being made in all directions to develop minerals required in connection with many trades and industries.

At the present time the Geological Survey collections amount to over 17,000 specimens, most of which are in triplicate, and over 4,000 microslides, together with an extensive library.

The following publications of the Geological Survey merit mention in this connection:

The Origin, history, and work of the Geological Survey of Western Australia.

Geological sketch map of Western Australia (1919 edition). Scale, 50 miles to one inch (1:3,168,000).

Map of Western Australia showing the chief localities at which useful minerals and artesian wells occur, together with the boundaries of goldfields and other mining districts. Scale, 50 miles to one inch (1:3,168,000).

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Map of Western Australia showing the four miles to one inch series of geological sketch maps and others issued since 1896. Scale, 75 miles to one inch (1:4,752,000). (See fig. 5.)

Mining handbook of Western Australia, by A. Gibb Maitland, with contributions by the staff. This volume includes chapters on general geology, mining law, suggestions to prospectors, and a glossary of geological and mining terms.

Bulletin No. 50 containing a general account of the geology of Western Australia.

Bulletin No. 64, in which will be found a revised account of the geology of the State (Rept. 58, p. 79), and its mining fields (Rept. 59, p. 92).

A summary of the geology of Western Australia (Mining Handbook, Chapter 1) is the most recent account of the geology of the State. It comprises 55 quarto pages, with numerous illustrations and a colored geological map of the State on the scale of 50 miles to one inch.

A list of publications of the Geological Survey may be obtained by applying to the government geologist.

GEOLOGICAL MAPPING IN THE NORTHERN TERRITORY

BY T. WAYLAND VAUGHAN

The geological map of the Northern Territory, north of latitude about 17° 20′ S., on a scale of 20 miles to one inch, by Doctor Wollnough,[24] gives the information available on the general geology of that region up to 1912. The report that the map accompanies contains a selected bibliography of the literature on the geology, except the southern part of the Territory (MacDonnell Ranges, etc.). As this work must be consulted by anyone studying the geology of the territory references will not be given here to maps published prior to 1912. The following is a list of papers accompanied by geological maps published in the bulletins of the Northern Territory subsequent to the report by Doctor Wollnough:

Bulletin No. 10, H. I. Jensen, Geological Report on the Darwin Mining District; McArthur River District; and the Barclay Tableland. 38 pp., 11 pls., 1914. Plate I is a black and white geological sketch map of the McArthur River country on a scale of 15 miles to 1 inch; plate II is a black and white geological map of the Sir Edward Pellew Islands on a scale of 5 miles to 1 inch.

Bulletin No. 11, Geo. J. Gray and H. I. Jensen, Report on the Maranboy tinfield: 32 pp., 2 colored geological maps, 1915. The first map is of the Marranboy tinfield: scale, 20 chains (1320 feet) to 1 inch; the second is a geological sketch map of Marranboy and King River; scale, 1 mile to 1 inch.

[24] Woolnough, W. G., Report on the geology of the Northern Territory: Northern Territory Bull. 4, 11 pls., 1 geol. map, 6 text figs., 1912.

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Bulletin No. 14. H. I. Jensen and others. Report on the country between Pine Creek and Tanami. Reconnaissance of Arnheim Land. Observations on country between Pine Creek and Newcastle waters: 44 pp., 12 pls., 1 colored geological map, 1915. The geological map is a revision of the one published by Woolnough in Bull. 4, but it is different; it is on a scale of about 22 miles to 1 inch and extends to 21° S. latitude.

Bulletin No. 15. Report on Yenberrie wolfram and molybdenite field: 4 pp., 1 colored geological map, 1916. The map is of a small area; scale, 10 chains (660 feet) to 1 inch.

Bulletin No. 16. H. I. Jensen, G. J. Gray, and R. J. Winters. The Geology of the Woggaman Province. Northern Territory of Australia: 72 pp., pls. 1-17b (maps, sections, and plans), and 15 figs. from photographs, 1916. This work contains seven geological sketch maps. Four of them, the Woggaman Province, the Margaret District; the Burrundie District and the Brock's Creek District are on the scale of 40 chains (2640 feet) to 1 inch. The scale of the Brock's Creek map is 10 chains (660 feet) to one inch; that of the country lying between Burrundie and the Mary River, approximately 2 miles to 1 inch; and that of the country from Brock's Creek to Fletcher's Gully, 5 miles to 1 inch.

Bulletin No. 19. H. I. Jensen. Report on the geology of the Agicondi Province of the Northern Territory: 36 pp., 13 pls., 1919. This work contains the geological sketch maps of Agicondi Province: Carter's Consolidated Mines, Pine Creek; Mt. Davis Quadrant; Mt. Diamond Copper Mines; Mt. Davis Copper Mines; and a Traverse from Mt. Diamond Mines to edge of granite near Coronet Hill Gorge.

I have not seen publications on the geology of the Northern Territory of later date than 1919. Although I may have missed later publications of importance, it is obvious that the Northern Territory is still largely geologically unexplored country. This is well shown on the map compiled by Jensen and published in Bulletin No. 14 of the Northern Territory.

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AREAL GEOLOGICAL MAPPING IN THE PHILIPPINE ISLANDS

By Warren D. Smith

The Philippine Government maintains a research institution known as the Bureau of Science. One of its divisions is the Division of Mines, the descendent of the former separate Philippine Mining Bureau. At the present time (August, 1920) there is only one technically trained person in the Division of Mines, a Filipino. In 1914 when the writer left the Philippine service there were six technically trained Americans in this division, one Filipino technical assistant in geology, two Filipno draftsmen, and a Flipino slide preparator. The staff then consisted of a geologist as chief of the division, a mining engineer, a petroleum geologist, a coal engineer, a metallurgist, and a half-time research worker—all from American institutions of recognized standing. Political changes in the Philippines disrupted this part of the Bureau of Science and it is only now that an attempt is being made to rehabilitate the work. The former chief of the Division of Mines with an American assistant is returning for a short period to lay plans for the future.

For geological work done previous to 1904, two men deserve special mention: the well-known Spanish geologist, Abella, and Becker, of the United States Geological Survey. Abella's principal field of work lay in the islands of Panay and Cebu where he devoted his attention largely to coal. He has left two books, one on each of these islands, which include generalized geological maps of the two islands on a rather small scale.

Becker's work was done at a very unpropitious time, in the year 1901, while the insurrection was in progress . Yet, in spite of his handicaps, he has left an excellent summary of all the Philippine geology then known. Becker spent about half of his time in the field.

In addition to a small-scale, generalized map of the whole archipelago and a topographic relief map of the whole region greatly generalized, the Division of Mines has also published detailed maps of the following districts: ·Cebu coal fields, Benguet gold field, Luzon; Tayabas oil field, Luzon; Masbate gold field on the island of the same name; and Batan coal field, Luzon. These maps are on several scales, such as 1:24,000 and 1:60,000. In addition, there have been issued several reconnais-

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FIGURE 1. Key to special maps of the Philippines. The numbered areas enclosed in black lines, date, scale, and author of the maps indicated, are shown in the following table:

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No.	Name of Map	Geologist	Date	Scale
1.	Cebu Island	Abella	1886	1:100,000
2.	Panay Island	Abella	1890	1:200,000
3.	Mancayan-Suyoc (Luzon)	Eveland	1905	1:24,000
4.	Batan Island	Smith	1905	1:24,000
5.	Compostela-Danao (Cebu)	Smith	1906	1:24,000
6.	Baguio (Luzon)	Eveland	1907	1:24,000
7.	Areroy (Masbate)	Ferguson	1909	1:20,000
8.	Mindanao Island	Smith	1910	1:750,000 Approx.
9.	Southwestern Luzon	Adams	1910	1:400,000
10.	Southeastern Luzon	Adams	1911	1:400,000
11.	Bondoc Peninsula, Tayabas (Luzon)	Pratt	1913	1:60,000
12.	Philippine Archipelago	Smith and others	1913	1:4 000,000 Approx.

sance maps on much smaller scales: southeastern Luzon, southwestern Luzon, part of the island of Mindanao, and several mineral resource maps. (See fig. 1.)

A Generalized Geological Map of the Philippine Islands has been issued as Plate 1, Volume VIII, A, No. 4, of the Philippine Journal of Science, 1913. By referring to this map, large blank spaces will be noted in the following areas: the Cagayan valley of northeastern Luzon; central Mindanao; the island of Palawan; and the island of Samar.

It has been recommended before, and will be repeated, that first a topographic map of the whole archipelago be begun. At the present time the Coast and Geodetic Survey and the United States Army have undertaken more or less of this work. But the Army work is not generally available; nor is it always done according to the ideas of geologists but rather for recording military features. Moreover, much of the work covers country which is at the present time of little or no interest to the geologist and the mining engineer. To complete a general topographic survey of the Philippine Islands would require at least twenty-five years and perhaps five or ten million dollars, but generalized geologic mapping by quadrangles or provinces should be undertaken at an early date. In the past geological work has been centered around some particular mining problem and it has not been possible to carry on the work uniformly over considerable areas. The difficulties of geologic mapping in the Philippines are almost unbelievably great to those unacquainted with the region. Specialists from the United States should be brought out to work on special problems, but a permanent staff to coördi-

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nate the work in the Philippines should be established in Manila. It is highly desirable to have both the financial and the technical coöperation of the United States Geological Survey.

The geological problems in the Philippines are by no means local. Much of the geology of the Pacific region will have to be interpreted with reference to the geological results obtained in the Philippines and work done elsewhere will aid in the solution of local problems.

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GEOLOGICAL MAPPING IN JAPAN, KOREA AND CHINA

By N. Yamasaki

The geology of the principal parts of the Japanese islands has been surveyed and mapped by the Imperial Geological Survey of Japan since 1879. The Survey has published two general geological maps and nearly 100 sheets of special maps in larger scale with text. The mineral resource maps of the islands are published by the same Survey. The survey and mapping of other large islands, Hokkaido, Formosa and Sakhalin, were carried on by their local governments. The first geological map of Korea, in scale 1:4,000,000, was prepared by Gottsche in 1886, and afterward larger and more detailed maps were issued by the geological surveys of Japan and Korea.

In China proper we have the classical works of Richthofen, whose maps cover most parts of North and South China, and even a part of South Manchuria. To a great extent Loczy has surveyed and mapped the inner provinces, which remained blank in former maps. In 1906 the maps of some parts of Shantung, Shansi, Shensi and Hupei were made by Willis and Blackwelder. Recently the Tokyo Geographical Society sent a number of geologists to undertake surveys of various districts of China. Already it has published 26 sheets of special maps and two general maps, with a text in Japanese.

Manchuria was mapped first by a Russian geologist, Ahnert, whose expeditions were made in the northeastern part of that district. The Geological Survey of Japan has published also a map of Quantung Peninsula. Recently the Geological Survey of the South Manchuria Railway Company has published a general geological map of South Manchuria. Beside these maps there were several maps of special survey published. The Geological Survey of Japan has published special maps of coal fields, oil districts, and many sheets of agronomic maps.

The following list includes the published geological maps of Japan, Korea, Formosa, and China:

MAPS ISSUED BY THE IMPERIAL GEOLOGICAL SURVEY OF JAPAN

1. General geological map of Japanese Empire, 1:1,000,000, Tokyo, 1902.
2. General geological map of Korea, 1:1,500,000, Tokyo, 1907.

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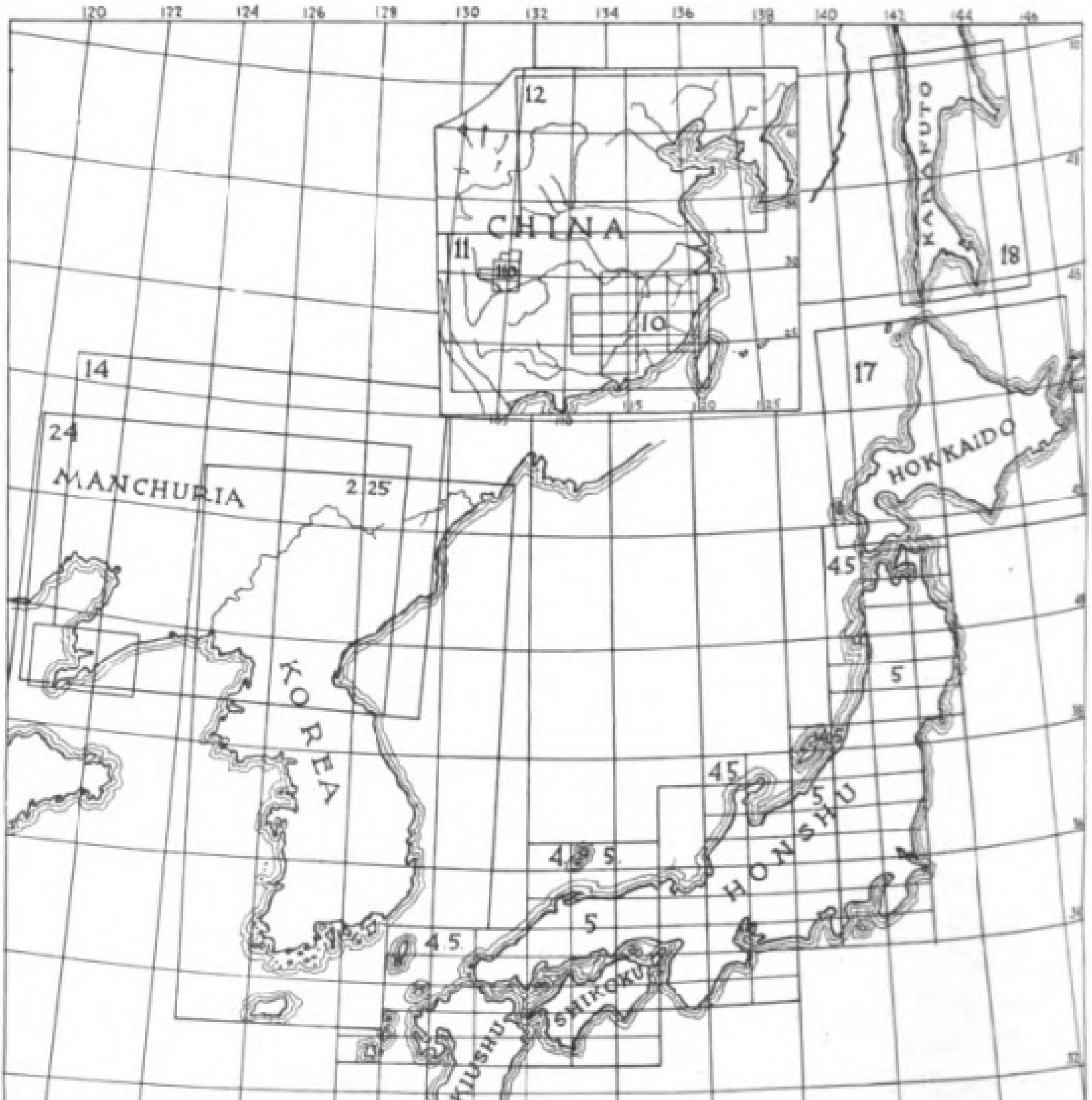


FIGURE 1. Map showing progress of geological surveys in the Japanese islands, Korea and China. The numbers marking the limits of the maps correspond with the numbers in the accompanying descriptive list.

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3. General geological map of Japanese Empire, including Korea, Sakhalin, Formosa, Liotung, 1:2,000,000, Tokyo, 1911.
4. Geological reconnaissance maps, 1:400,000, 5 sheets, Tokyo.
5. Special geological maps, 1:200,000, 99 sheets, Tokyo.
6. Mineral resource maps, 1:400,000, 5 sheets, Tokyo.
7. Mineral resource map, 1:2,000,000, Tokyo, 1911.
8. Geological map of the southern part of Liotung Peninsula, 1:1,-000,000, Tokyo, 1905.

MAPS ISSUED BY THE TOKYO GEOGRAPHICAL SOCIETY

9. Geographical research in China, handy geological map of Central and South China, 1:7,500,000, Tokyo, 1917.
10. Geographical research in China, geological map of Central and South China, Part 1, 1:400,000, 17 sheets, Tokyo, 1917; Part 2, 1:200,000, 9 sheets, Tokyo, 1917.
11. General geological map of Central and South China, 1:2,000,000, Tokyo, 1920.
12. General geological map of North China, 1:2,000,000, Tokyo, now in press.

MAPS ISSUED BY THE GEOLOGICAL SURVEY OF SOUTH MANCHURIA RAILWAY COMPANY

13. Geological map of the southern part of Liotung Peninsula, 1:200,-000, Dairen, 1915.
14. Geological map of South Manchura 1:1,000,000, Dairen, 1918.

MAPS BY F. VON RICHTHOFEN

15. Geological map of North China, 1:750,000, 13 sheets, Berlin, 1885.
16. Geological map of South China, 1:750,000, 14 sheets, Berlin, 1912.

MISCELLANEOUS MAPS

17. Geological map of Hokkaido, 1:600,000, Sapporo, 1918, by Yoshichika Oinouye.
18. Geological map of Karafuto, 1:1,000,000, Toyohara, 1908, issued by the Government of Karafuto (Sakhalin).
19. Geological map of Taiwan (Formosa), 1:300,000, Taihoku, 1911, issued by the Government-General of Taiwan.
20. Geological map of East Manchuria, St. Petersburg, 1904, by Ahnert.
21. Geological map of Hokkaido, 1:1,200,000, Sapporo, 1896, by Kotoro Jimbo.
22. Count Béla Széchenyi's expedition, geological map, 1:5,000,000, Budapest, 1893, by L. von Loczy.
23. Research in China, geological map, 1:125,000, Washington, 1906, by Bailey Willis.
24. Geological map of South Manchuria, 1:800,000, Ryojun, 1906, issued by the Government of Kwanto.
25. Geological map of Korea, 1:1,000,000, Seoul, 1920, issued by the Geological Survey of the Government-General of Korea.

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CATALOG AND INDEX MAP OF THE AREAL GEOLOGICAL MAPS OF EASTERN SIBERIA

By L. M. Prindle and H. B. Sullivan, Section of Foreign Mineral Reserves, United States Geological Survey

PREFACE BY BERTRAND L. JOHNSON

The extent of Russia's geological investigations in Eastern Siberia is not realized by most American geologists. Geographical and geologic investigations of the Russian Far East began in the seventeenth and eighteenth centuries and have continued down to the present date. Many reports have been published covering the results of the various expeditions. A bibliography and an index map to the areal geologic maps of Eastern Siberia have been prepared by Messrs. L. M. Prindle and H. B. Sullivan of the Section of Foreign Mineral Reserves of the United States Geological Survey. They show some of the areas which have been mapped geologically, and list the reports covering these areas, which contain the geologic maps indicated on the index map (fig. 1). The compilation is obviously incomplete, as Mr. Prindle, who made the search of the available literature and prepared the list of geologic maps on which the index map is based, was restricted in his search for geological maps to the reports available in the library of the United States Geological Survey and the other libraries in Washington. The results obtained, while they will be surprising to many geologists, will undoubtedly be supplemented by consultation of other reports not available in Washington. The preparation of the index map is the work of Mr. Sullivan.

The manuscript submitted by Prindle and Sullivan gives full descriptive details for geological maps, including title in Russian and in English, location, scale, area covered, and the geological formations shown. Limitations of space make it necessary to reduce this manuscript to a mere list of publications in which these maps occur.

PUBLICATIONS WHICH INCLUDE GEOLOGICAL MAPS

Geological Explorations in the Auriferous Districts of Siberia, which includes maps of the following: Achinsk, Minusinsk and Amur regions; Yenisei, Tsipikan, Lena, Zeya, Selemjda and Amur Maritime auriferous districts; Bur-

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einsk-Zavitmsk lignite region; basins of Chirimba and Vangash rivers; gold-producing region of the Olekma-Vitim region; central part of the Patom mountain country; Lena-Vitim mountain country; Olekma-Vitim auriferous system; upper portions of the Chichatka, Urkan, Urusha and Nyukzha rivers: Basins of the left tributaries of the Big Oldoi, and the right tributaries of the Giloui and traverse by trail to the Amur; Stanovoi (Yablonoi) range between Rivers Sutam and Zeya; Amur-Zeya Divide; Banks of the Amur north from Blagovyeshchensk; Tynda River; basin of the Celemdzha River; and lower part of the Amgun River.

Geological and Mining Investigations along the Siberian Railway, which include maps of the following: Lignite basin of the Tchoulym and Serech rivers; middle Chulim coal-bearing basin; Districts of Krasnoyarsk, Kansk and Achinsk, Yenisei Province; Districts of Kanska and lower Udinsk; Angara River from the Oka to the Yenisei; Nijni-Udinsk District of the Irkutsk Province; parts of the Balagansk and Irkutsk Districts; areas between the upper parts of the valleys of the Angara and Lena River; Celenginsk, Trans-Baikal, and Nerchinsk districts; Amur-Zeya Divide; Ussuri River between Krasnoiarsk and Khabarovka; and upper basins of the Ussuri, Iman and Bikir Rivers.

Bulletins of the Geological Committee, which include maps of the Peninsula Muraverv-Amur and the Ruskii Island; Suchan coal deposits; the region along the Suchan Railroad; Schmidt Peninsula in northern Sakhalin; Russian Sakhalin; northwestern part of Copper Island; auriferous area of the Volchya (Wolf) River; and Anadir Expedition of 1912 and 1913.

Maps from Miscellaneous Sources: Imperial Mineralogical Society includes maps of the area about Lake Shire and shore areas of Lake Baikal; Die Neueren Fortschritte in der Erforschung der Goldlagerstätten Sibiriens includes map of Übersichtskarte der Goldlagerstatten des Kusnetzky-Alatau und der Sajanen and Versuch einer Darstellung der geologischen Strukturlinien Sibiriens Zusammengestellt n. d. Darstellung v. E. Suess, d. geologischen Karte V. R. Reutovsky u. neueren russischen Augnahmen; Memoirs of the Imperial Russian Geographical Society includes map of the Gold Mines of the Olekma system, and map from the

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Tikhono-Zadonski Mine on the River Nugri to the Village of Podvolochni on the Chita; Verhandlungen der Russisch-Kaiserlichen Mineralogischen Gesellschaft zu St. Petersburg includes map of Geognostische Karten und Profile eines Theils des Lena-Stroms und des Werchojanskischen Gebirges, 1850; Marekanite deposits in the vicinity of Okhotsk and geological sketch of the western shore of the Okhotsk Sea, includes maps of the area including deposits of Marekanite; and Tectonic lines of the coastal regions of the Okhotsk Sea between Nikolaievsk and Oktrotsk; Annals des Mines contains map entitled Carte Tectonique et Metallogenique de la Sibérie; Memoirs of the Imperial Academy of Sciences contains geological traverse map of New Siberia Islands and ports of the Yana, Lena, Olensk and Anabara rivers; Beiträge zur Kenntniss des Russischen Reiches u. der Angrenzenden Länder Asiens contains map of Der Awatscha-Bai (Kamchatka); Peterman's Mittheilungen contains Geologische Karte (Kamchatka); Bulletin of the East Siberian Section of the Imperial Russian Geographical Society includes map of the Peninsula of Kamchatka; Publication of the Mining Department of Russia, 1905, contains geological map of Siberia and the useful minerals.

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THE GEOLOGICAL SURVEY OF ALASKA

By Alfred H. Brooks, Geologist, United States Geological Survey, Washington, D. C.

During the Russian occupation of Alaska, ending in 1867, the investigation of its geology did not go beyond the random notes of the explorer made by those untrained in the science. The most important definite scientific facts then obtained were fossils collected at a number of localities, which eventually found their way to European museums. Owing to the conscientious labor of Grewingk, Professor of Geology at the University of Dorpat, all these geologic data were compiled and coördinated.[1] Though he had never seen any part of Russian America, Grewingk prepared a geologic map of such parts of this vast region as had then been explored. Crude as this map is, it is not without merit and represents the first attempt to give cartographic presentation of Alaska geology. Indeed it remained the only general geologic map of Alaska for over half a century.

During the first thirty years of our occupation of Alaska no geologic surveys were made of the Territory, but much geologic knowledge of it was obtained through the work of various explorers. Most prominent among these was Doctor William H. Dall, who carried on his researches first as leader of the scientific corps of the Western Union Telegraph Expedition, and later under the auspices of the Smithsonian Institute and the Coast Survey. Among other geologists who rendered valuable service in this field are W. P. Blake, I. C. Russel, and C. Willard Hayes, and in the adjacent Canadian territory George W. Dawson and R. G. McConnell.

The work of the United States Geological Survey in Alaska was begun under a small appropriation in 1895, when Dr. William H. Dall and Dr. George F. Becker studied the coal and gold resources of its Pacific seaboard. In the following year an investigation of the gold placers of the Yukon was made by J. E. Spurr, H. B. Goodrich, and F. C. Schrader.

The public interest aroused by the Klondike gold discovery led in 1898 to a more liberal grant of funds, when the systematic surveys and investigations of Alaska were begun by the

[1] Grewingk, C., Beiträge zur Kentniss der orographischen und geognostischen Beschaffenheit der Nord-west Küste Amerikas, mit den anliegenden Inseln (with geologic and other maps). St. Petersburg, 1850.

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United States Geological Survey. This annual appropriation, since continued, was made specifically for the investigation of the mineral resources of Alaska. Hence the greatest emphasis has had to be placed on economic geology. The annual grants varied from $25,000 to $100,000, and the appropriation up to the close of 1920 has totaled $1,788,189. Less than half of this fund has, however, been allotted to geologic investigations, the balance being used chiefly for topographic surveys, with small amounts for stream gauging and the collection of mineral statistics.

When the Geological Survey began this work inland Alaska, except for the valleys of some of the larger rivers, was almost unknown. Therefore, the determination of the larger geologic and topographic features was necessary before systematic areal surveys could be intelligently carried out. A network of such explorations was planned and the making of these was the principal task up to 1903. These explorations carried out under great physical difficulties, generally afforded but few opportunities for detailed investigations. They served, however, to determine some of the larger stratigraphic units, and their distribution, as well as to block out the principal tectonic provinces. This made it possible in 1904 to prepare a summary of the geology and geography[2] of the entire Territory, together with a geologic map on a scale of 200 miles to the inch. This work, while very incomplete, served to correlate the large features of the geology of Alaska with those of the rest of North America.

Meanwhile, areal geologic surveys were begun in 1900 and have been continued to the present day. The first work of this kind was of the gold placer fields in the Seward Peninsula and of the copper-bearing area of the Copper River basin. Since then all the known mineral-bearing areas have been mapped. Detailed geologic surveys, begun at Juneau in 1903, have since been extended as fast as the funds available would permit. Thus far they have been confined entirely to the important mining districts, most of which have been covered.

The areas covered by the several kinds of geologic surveys are shown on the accompanying map of Alaska (fig. 1). Three types of work are recognized to accord with the publication scale, which roughly indicates the degree of refinement on which the field investigations have been made. The standard publica-

[2] Brooks, Alfred H., The geography and geology of Alaska: U. S. Geol. Survey Prof. Paper 45, 1906.

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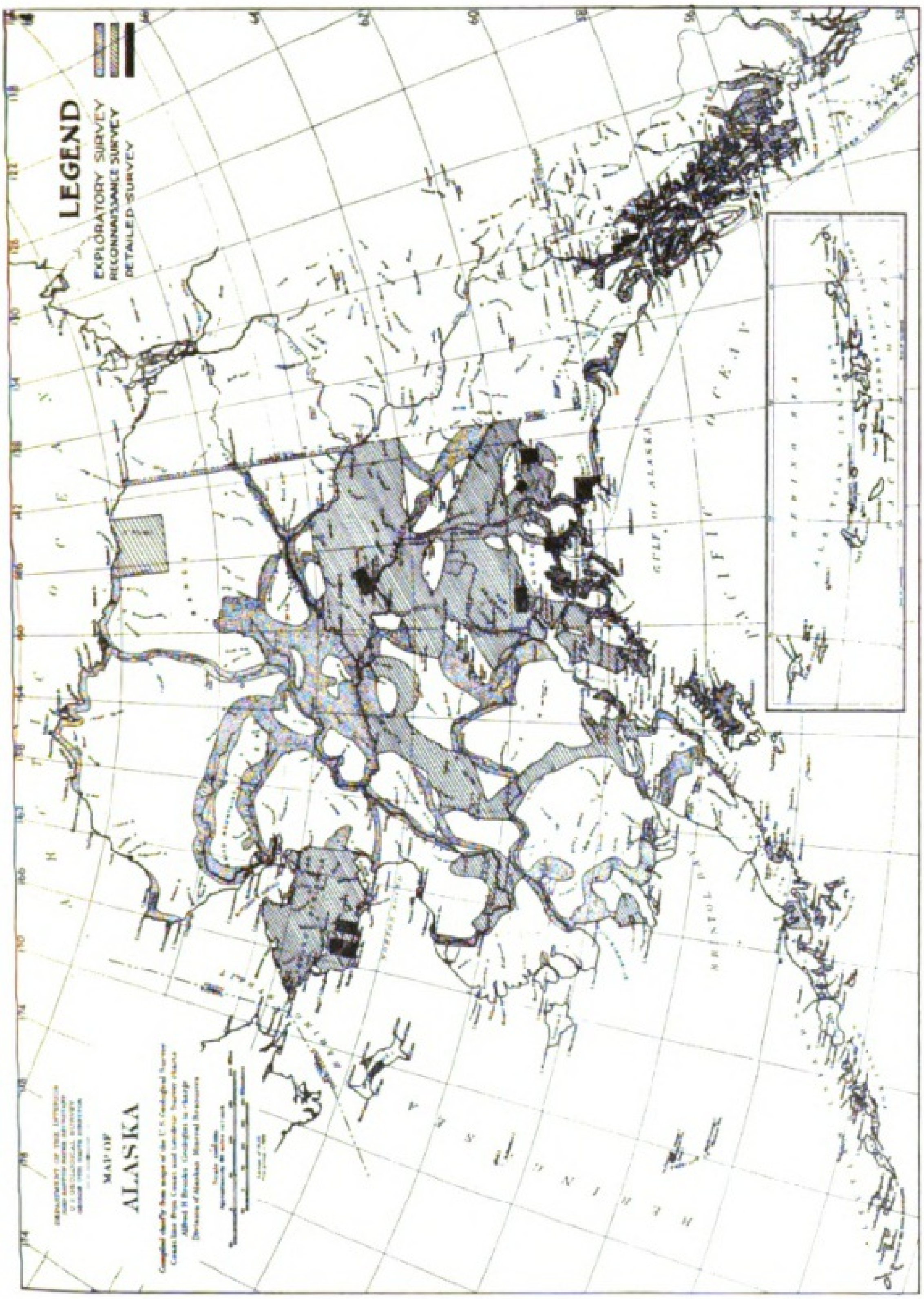


FIGURE 1. Map of Alaska showing status of geological surveys.

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tion scale for the exploratory surveys is 1:500,000. There are, however, many areas which have been mapped on a smaller scale. Up to the close of 1920 a total area of 73,000 square miles had been mapped in Alaska on the exploratory scale. A project is also under way of issuing a series of maps of Alaska on a scale of 1:500,000 with the purpose of illustrating the geology of the different provinces. None of these maps has been published but one has been compiled of the Seward Peninsula and others are under way. The geologic reconnaissance maps are published on a scale of 1:250,000. At the close of 1920, 109,000 square miles of Alaska had been mapped on this scale. To meet the immediate demands of the miner and prospector these reconnaissance maps have, so far as the publication funds permitted, been issued as soon as the field work in any special region was completed. As a result the published maps are for the most part of very irregular outline.

The 1:250,000 scale has been adopted for the standard geologic map of Alaska. Though called reconnaissance maps, in their final form of publication they will be accurate to the scale, which does not, however, permit delineating the geology to the same degree of refinement as can be done on the detailed maps. The standard unit of publication is a quadrangle measure 4 degrees of both latitude and longitude.[3] Standard geologic maps will then be published as quadrangles, and included in bulletins which will contain text descriptions.

The detailed geologic maps are published on a scale of 1:62,500. The standard of accuracy and refinement are the same as for similar maps made in the United States proper. Detailed geologic maps of Alaska now cover a total area of 5,400 square miles. The making of such maps, including the base, is very expensive. For the present no attempt is made to survey regular quadrangles but the field work is confined to the areas of greatest economic importance, irrespective of their outline. The results are published as bulletins and professional papers.

[3] The system of numbering of standard geologic and topographic maps of Alaska (scale 1:250,000) is as follows: The first two digits of the number are the same as those of the parallel of latitude which bounds the quadrangle on the south. The third digit is determined by the distance of the quadrangle from the eastern boundary of Alaska. For example, Quadrangle No. 601 is the one lying adjacent to the Canadian boundary on the 60° parallel. The detailed maps (scale 1:62,500) receive a letter in addition to the number of quadrangle in which they lie.

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Paleontologic field work was begun in Alaska in 1903, when Arthur Hollick commenced study of the Cretaceous and Tertiary plant-bearing beds of the Yukon. In the following year, T. W. Stanton, in company with George C. Martin, inaugurated the investigation of the Alaska Mesozoic. Other paleontologists who have done field work in Alaska are E. M. Kindle, Edwin Kirk, and George H. Girty. In addition to their field work, these paleontologists have greatly aided the determination of Alaska stratigraphy by studying the fossils collected by others. There are now in hand very large collections of fossils from Alaska which await detailed study. Plans for the monographic treatment of this material are under way but the only project that is nearing completion is the description of the Upper Cretaceous and Tertiary floras by Mr. Hollick. Meanwhile, George C. Martin is preparing a summary of Mesozoic geology of Alaska.

The first geologic map of Alaska, prepared in 1904, was revised and incorporated in Bailey Willis' map of North America issued in 1912. This is the latest published geologic map of Alaska, but one is in course of compilation on a scale of 1:2,500,000. There is also now in print a shaded relief map (scale 1:2,500,000) of Alaska by John W. Renshawe which admirably delineates its physiographic features. The writer is engaged in preparing a brief treatise on the tectonic history of Alaska.

The investigations and surveys recorded above were made under the auspices of the United States Geological Survey. Owing to a shortage in printing funds there are now many unpublished data on hand. The Geological Survey has issued upwards of one hundred publications dealing with the geology of Alaska.

In addition to the above there must be recorded some important geologic investigations made under other auspices. Mr. Leffingwell devoted some six years to geologic investigations of the north Arctic slope in the course of which he mapped an area of 6,000 square miles.[4] This work was done entirely on his own initiative and expense.

Extensive Alaska glacial studies have also been carried on under various auspices and by many geologists. The earlier work of this character was by John Muir, G. Frederick Wright,

[4] Leffingwell, E. de K., The Canning River region, Northern Alaska: U. S. Geol. Survey Prof. Paper 109, 1919.

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Harry Fielding Reid, and I. C. Russel. These investigations were summarized by G. K. Gilbert, who also made personal observations in the field, and by George M. Davidson. The recent more exhaustive studies and detailed surveys of the Alaska glaciers are chiefly by R. S. Tarr and Lawrence Martin.

In spite of the great progress made during the last quarter of a century in the geologic mapping of Alaska there still remains an area of some 300,000 square miles whose geology is almost unknown. Until this is mapped there will remain a hiatus in geologic knowledge which must necessarily lead to faulty generalizations.

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GEOLOGICAL MAPPING IN THE CANADIAN CORDILLERA

By Victor Dolmage, Geologist, Canadian Geological Survey

The great bulk of geological work in British Columbia and Yukon Territory has been performed by the Geological Survey of Canada. Geological work was begun in the Canadian Cordillera in 1859 when Hilary Bauerman began a traverse along the forty-ninth parallel. No maps, however, accompany his report, which appeared in 1884. Actual geological mapping was begun in 1871 by James Richardson, who studied the coalfields of Vancouver Island.

From 1871 to the present over 90,000 square miles have been geologically mapped, and about 4000 miles of water routes traversed. About 42,800 square miles of this was done by early explorers on a scale of eight miles to the inch, and though some of it may be classed as good reconnaissance survey, much of it is only exploratory work. About 3100 square miles of good reconnaissance was done on a scale of six miles to the inch by more recent workers. About 32,600 square miles were done on a scale of four miles to the inch, all of which work is good reconnaissance survey; and some of it may even be classed as detailed work. About 10,200 square miles were done on a scale of two miles to the inch, all but a small portion of which is detailed work. About 5800 square miles were mapped on a scale of one mile to the inch, all of which is detailed work, and much of it very detailed. About 163 square miles of refined work was done on scales ranging from 400 to 2640 feet to the inch.

From the standpoint of the character of the work produced, mapping in this region naturally divides itself into two periods. The division, which is by no means a sharp one, comes shortly after the beginning of the present century. Prior to that time most of the work was of an exploratory or reconnaissance nature, whereas nearly all the work since has been detailed. The maps of the earlier period embrace huge areas done on scales of eight or four miles to the inch, while in the later period smaller areas were undertaken, and were much more thoroughly traversed. The geographic base maps used by the earlier workers were inferior, and were usually prepared by the geologist in conjunction with his geological work. The tendency to extend

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geological boundaries into unexplored regions was greater in the earlier period, but not confined to it. The men of the earlier period were essentially stratigraphers and accented that phase of geology, devoting much of their time to areas underlain by sedimentary rocks; in the second phase more stress was laid upon petrography, and the study of the igneous rocks. Economic studies during the earlier period were largely of coal areas, and placer ground, while in the second period more attention was devoted to metalliferous deposits.

On the whole the work of the two periods differed in kind rather than quality, and it can be said with emphasis that the earlier workers, such as George M. Dawson, A. R. C. Selwyn, R. G. McConnell, James Richardson, James McEvoy and others laid with skill the broad and secure foundations upon which all subsequent work must be built. Dawson's work was of an exceptional character, and will always remain the basis for future work in almost every part of the Canadian Cordillera.

Three kinds of maps were produced in the first period. The most primitive were made by traversing the great inland water routes and either mapping the geological formations encountered, or, as in most cases, merely sketching in the topography and describing the geology. In this way Selwyn examined some of the proposed routes of the Canadian Pacific Railway in 1871 and 1875, which included parts of the Fraser, Chillacoo, Parsnip, Pine and Peace rivers. Dawson examined the Yukon, Stikine, Skeena and Peace, and McConnell the Yukon, Liard, Porcupine, Omineca, and Finlay rivers.

The second type of map produced by the workers of this period was one which covered large areas from 6000 to 30,000 square miles in extent on a scale of from four to eight miles to the inch. The work which involved a great deal of topographic surveying, as well as geological mapping, was usually completed in one or two seasons, and was, therefore, of necessity somewhat sketchy. The geology was mapped usually quite accurately along the lines traversed, and the formational boundaries were then extended into the intervening areas, a practice which detracted from rather than added to the value of the map. As examples of the earlier maps of this type might be mentioned Dawson's map of the southern portion of British Columbia from Okanagan to Harrison Lake, and a similar map by the same author embracing over 30,000 square miles lying between longitude 122° and 127° and between latitude 51° and 55°.

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Towards the end of this period the maps of this type were considerably improved by having much more detailed and accurate work done on them, for example Joseph Keele's map in the Mayo Lake district of the Yukon and J. C. Gwillim's map in the Atlin district. This type of map reached its perfection in Dawson's Kamloops and Shuswap sheets published in 1895 and 1898, respectively, on a scale of four miles to the inch.

The third kind of map produced in the early period was a detailed map on a scale of four miles to the inch, embracing a small area in some coal-bearing district. Examples of this type are Richardson's map of the Nanaimo district, published in the Report of Progress for 1876-77, James McEvoy's, D. B. Dowling's, and W. W. Leech's maps of the Crow's Nest district, published at a later date.

The second period began with the work of R. G. McConnell, R. W. Brock, O. E. LeRoy, Charles Camsell, and others. The first map of this period, Brock and McConnell's West Kootenay Sheet, was a "four mile" map embracing over 6000 square miles, and is only distinguished from the maps of the earlier periods by having a greater amount of accuracy and detail resulting from more complete traversing, and application of petrography, which differentiated a number of types of igneous rocks, which would have been mapped by the earlier workers in one color. After this work came a more distinct change in the class of work undertaken, in the methods employed and, consequently, in the results obtained. All of the workers above mentioned devoted themselves to the close detailed study of mineral deposits and their immediate vicinity, and after 1907, it became for a time the policy of the survey to do this class of work. There resulted a great number of small maps covering a few hundred square miles at most, on scales ranging from a fraction of a mile to two miles to the inch. These were executed in great detail, and, though a topographic division had not yet been established in the Geological Survey, accurate contour maps were used for most of this work.

As examples of this type of work we have Brock's "Boundary Creek Mining District" published in 1905 on a scale of one mile to the inch; the "Special map of Rossland" on 400 feet to the inch, "Rossland Mining Camp" on 1200 feet to the inch, and "City of Rossland" on 1600 feet to the inch, published in 1909; also "Klondike Mining District" on one mile to the

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inch in 1905, and his "Whitehorse Copper Belt" on 400 feet to the inch and one mile to the inch in 1909; Camsell's "Princeton Coal Basin and Copper Mountain Mining Camp" on one-half mile to the inch published in 1906, his "Hedley Mining Camp" on 1000 feet to the inch in 1908, and his "Tulameen" area on one mile to the inch published in 1911; LeRoy's "Nelson District" published in 1904, his "Phoenix" maps and his "Mother Lode and Sunset" published in 1911, and D. B. Dowling's "Cascade Coal Basin" issued 1907.

The only work done at this time on a scale of four miles to the inch are some shore maps extending from Vancouver to Burke Channel by LeRoy, R. P. D. Graham and Austin J. Bancroft. This first phase of the second period may then be considered one of intensive economic work on mineral deposits, and the results obtained were of economic rather than purely scientific value.

Following this period of intensive economic work came one in which, though economic geology still took a prominent part, other phases of the science such as physiography, structural geology, stratigraphy and petrology received much attention. This period began with Daly's work on the Forty-Ninth Parallel, which differed markedly from the work just described, first because the work was of a different nature, having a different object in view and being done under conditions necessitating the use of less precise methods, and second, because of Daly's intense interest in the theories of petrogenesis which he was at that time evolving. The undertaking was a large one, the time was limited, adequate topographic base maps were not always available, no geologically trained assistant was employed and the work was confined to a narrow strip along a straight line where outcrops were sometimes scarce and fossiliferous exposures still more rare. These conditions necessitated hasty work with an insufficient number of traverses, and as Daly himself says, the quality of the work lies half way between reconnaissance survey and detailed survey. As a natural result the maps now published on the mile-to-the-inch contour maps of the Boundary Commission do not possess the accuracy they would suggest and already subsequent workers have had to make some important changes in the structure and stratigraphy. Daly's later work on the Shuswap Sheet and along the Canadian Pacific Railway is similar in character to that just mentioned.

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About this time the topographic division of the geological survey was organized, and the excellent contour base maps it produced had a decidedly favorable influence on the geological mapping done.

A considerable amount of "four to six mile" work, partly of a reconnaissance nature and partly more detailed, was done during the period; for example C. H. Clapp's map of "Southern Vancouver Island" published in 1911; D. D. Cairnes' "Upper White River District," Yukon, issued in 1915; C. W. Drysdale's "Bridge River Area," 1915; S. J. Schofield's "Cranbrook Area," 1912 and 1915; and J. D. MacKenzie's map of "Graham Island" published in 1916. All of these maps cover relatively large areas and some of the geological boundaries mapped were not traced out in the field. Quite a number of "two-mile" maps somewhat more refined than the "four-mile" maps were also produced by these geologists, good examples of which are: the "Field" map area by J. A. Allen issued in 1915; the "Tantalus Coal Area" and the "Yukon Alaska International Boundary," both by Cairnes and issued in 1915; "Texada Island" by McConnel; the "Hazelton District" by J. J. O'Neill; and the "Blairmore Map Area," Alberta, by Bruce Rose and W. W. Leach. A great deal of work was also done on a scale of one mile to the inch and less than a mile to the inch, all of which was done in great detail and with considerable accuracy but which was not necessarily directly related to mineralized areas. Examples of this class of work are the "Nanaimo," the "Victoria," and the "Soanish" sheets by C. H. Clapp, and the "Duncan," and "Sooke" sheets by Clapp and H. C. Cooke all of which cover areas in southern Vancouver Island. Also the "Wheaton District," Yukon, by Cairnes issued 1917, the "Beaverdell Area" by L. Reinecke issued 1915, the "Franklin Mining Camp" published in 1914 and the "Ymir Area" published in 1916 both by C. W. Drysdale, J. D. MacKenzie's "Southern Graham Island" published 1916 and his "Flathead Coal Area" published 1917. Schofield's "Ainsworth" map on a scale of 2000 feet to the inch done in 1915 and published in 1918 is also a good example of this class of work. Many small maps on a larger scale covering mineralized areas are also incorporated in the reports by these men. The period as a whole may be characterized as one in which *all* the phases of geology received about equal attention.

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This policy which has been in effect since 1918 is to confine the work to areas of known economic importance *or* to areas at present within easy reach of transportation.

The work in these localities is being carried on by a younger group of men having a similar training to those above mentioned and the work is of a similar character.

In carrying out this policy, Schofield has mapped the Britannia mineral belt lying between Howe Sound and Burrard Inlet. J. J. O'Neill began and George Hansen is completing an area in the Salmon River District of northern British Columbia. W. E. Cockfield has just published a sheet on a scale of four miles to the inch embracing Sixty Mile and Ladue rivers in the Yukon District and is at present engaged in mapping in the vicinity of Mayo Lake. W. A. Johnson has just completed a detailed investigation of the Fraser Delta. Victor Dolmage has just completed a shoreline map of the west coast of Vancouver Island from Barkley Sound to Cape Scott which was executed on a scale of one mile to the inch. In 1917 Camsell made a geological map of a section along the Pacific Great Eastern Railway from Squamish to Lillooet. B. R. McKay began and W. A. Johnston will continue a detailed map of superficial geology in the Cariboo gold placer belt in central British Columbia. C. E. Cairnes is completing a map of an area along the Coquihalla River which was begun by Camsell in 1919. M. F. Bancroft is engaged in mapping a large area in the Slocan district southeast of Revelstoke. J. R. Marshall is continuing the deatiled mapping in the Elk River district in eastern British Columbia which had been carried on previously by Bruce Rose.

The progress made in geological mapping of the Canadian Cordillera is shown in the accompanying map (fig. 1).

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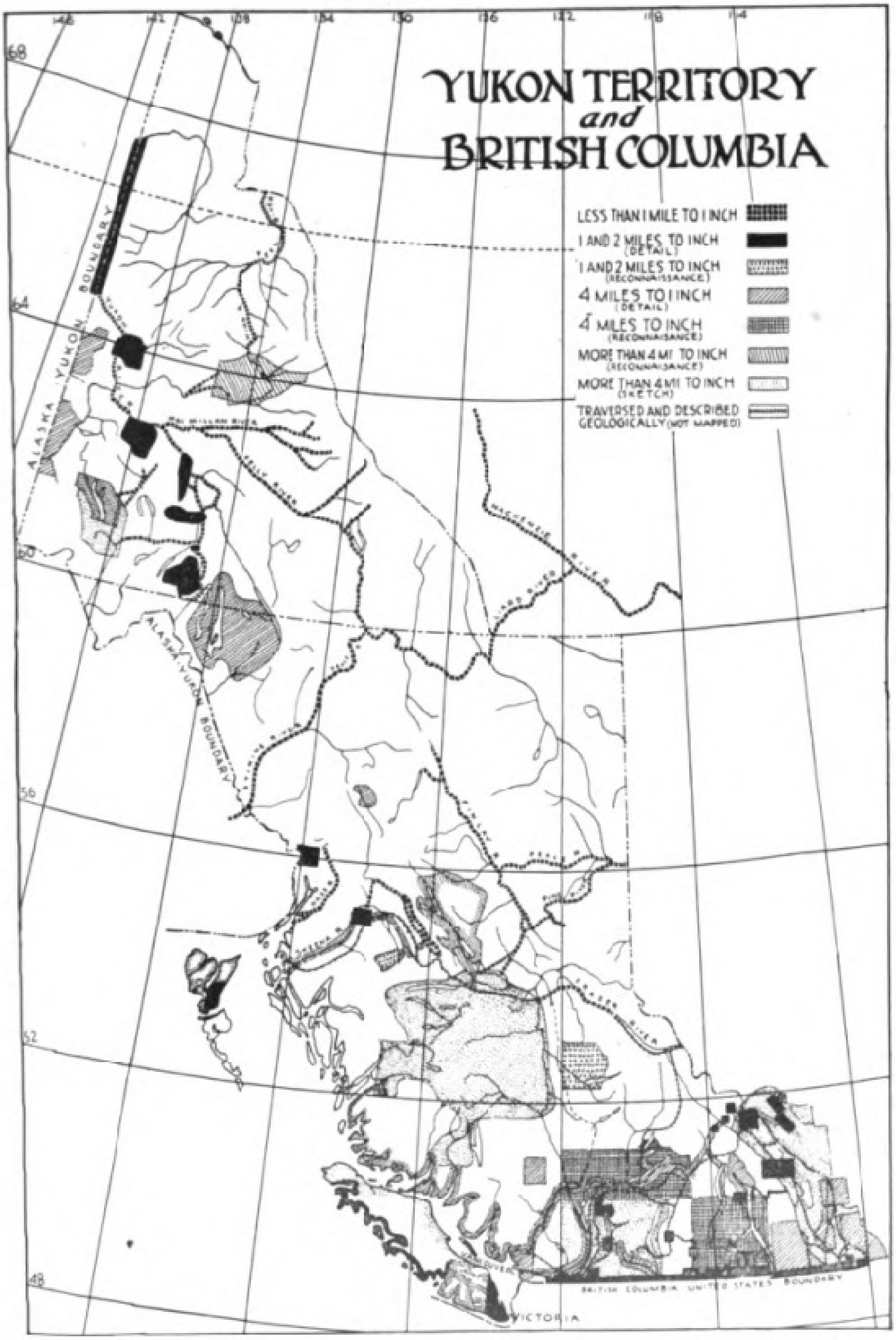


FIGURE I. Index map of geological work done in Yukon Territory and British Columbia up to 1920.

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GEOLOGICAL MAPPING IN THE WESTERN PART OF THE UNITED STATES, CENTRAL AMERICA, AND THE WEST INDIES

By T. Wayland Vaughan

WESTERN PART OF THE UNITED STATES

The data here given are for the States of South Dakota. Montana, Wyoming, Colorado, New Mexico, Texas east of Pecos River, Idaho, Utah, Arizona, Nevada, Washington, Oregon, and California.

For an account of the sources of data on the geological cartography of the United States, and also on that of Canada, Mexico, Central America, and the West Indies, Willis's Index to the stratigraphy of North America[1] should be consulted, as it contains references to virtually all the important geological maps of those regions published prior to 1911. The bibliographies of North American geology published annually by the United States Geological Survey contain references to geological maps and information on maps issued since Willis's work went to press can be found in them.[2] Another valuable work of reference is O. E. Meinzer's[3] Bibliography and index of the publications of the United States Geological Survey relating to ground water. The list of publications of the United States Geological Survey, which is indexed, will help in finding references to maps published by the Federal Survey.

The accompanying map (fig. 1) taken from the Forty-first annual report of the Director of the United States Geological Survey shows the areas covered by geological maps published by the United States Geological Survey prior to July, 1920, but a considerable number of other maps published or in preparation need to be mentioned.

The following are notes, according to States on other maps:

[1] U. S. Geol. Survey Prof. Paper 71, 894 pp., 1912. Prepared to accompany the Geological Map of North America, compiled by Bailey Willis and G. W. Stose, scale 1:5,000,000, 1911.

[2] The U. S. Geol. Survey Bull. Numbers of these bibliographies, all by J. M. Nickles, beginning with 1910 are as follows: For 1910, No. 495; 1911, No. 524; 1912, No. 545; 1913, No. 584; 1914, No. 617; 1915, No. 645; 1916, No. 665; 1917, No. 684; 1918, No. 698.

[3] U. S. Geol. Survey Water-Sup. Paper No. 423, pp. 167, 15 pls., 1917.

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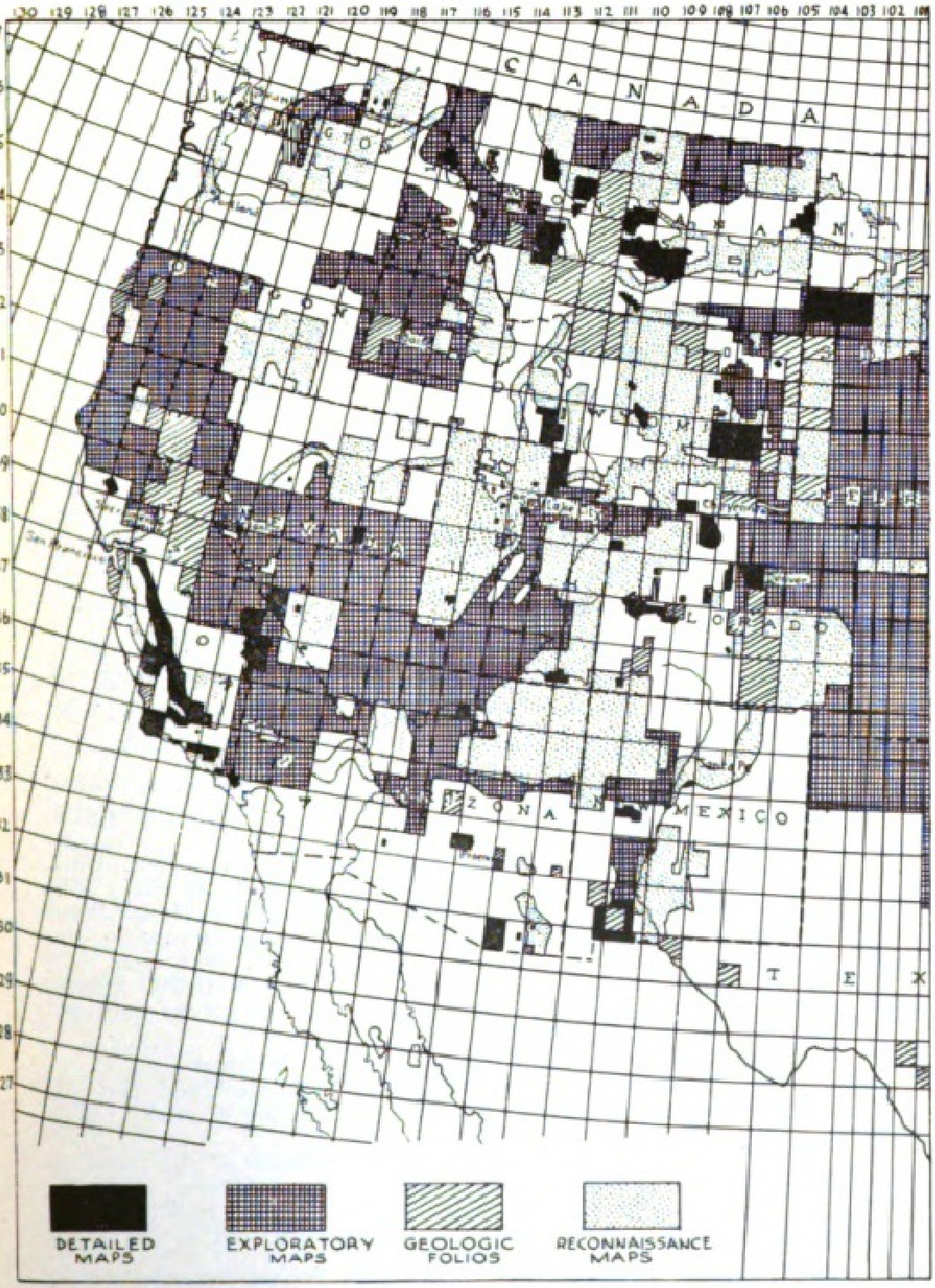


FIGURE 1. Map of the western part of the United States showing areas covered by geological maps.

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South Dakota. No general geological map of the State has been published, but there is a large amount of data available on the areal geology of the State. The key-map (fig. 1) shows the status of the work done by the Federal Survey. A bibliography of the Black Hills[4] by O'Hara contains a list of publications on that part of South Dakota that needs consideration in the present connection.

Montana. C. H. Clapp, director, Montana Bureau of Mines and Metallurgy, has in course of preparation a map of the State in two sheets. The eastern sheet will probably be published in 1921. More field work is to be done on the western half of the State before a map is published.

Wyoming. Compilation by J. D. Sears on scale of 1:500,000. Manuscript map completed but not revised. Date of publication uncertain.

Colorado. R. D. George. Geological map of Colorado, 1913. Scale: 1:500,000 approximately 8 miles to the inch.

Texas, west of Pecos River. The only geological maps of that part of Texas west of Pecos River published by the United States Geological Survey are the El Paso and Van Horn folios, both by G. B. Richardson, each on a scale of 1:125,000, but the University of Texas has issued several reports accompanied by geological maps since 1910. They are as follows:

Review of the geology of Texas by J. A. Udden, C. L. Baker, and Emil Böse: Univ. of Texas Bull., 1916, No. 44, 164 pp., geological map on scale of 1:1,500,000.

Notes on the geology of Glass Mountain by J. A. Udden: Univ. of Texas Bull. No. 1753, Bur. Econ. Geol. and Technol., 59 pp., 3 pls.; Geologic exploration of the southeastern Front Range of Trans-Pecos Texas, by C. L. Baker and W. F. Bowman: *Ibid.*, pp. 63-177, 9 pls., and 1 colored geological map on a scale of 1:380,160 = 1 inch to 6 miles, 1917. This map covers parts of El Paso, Jeff Davis, Reeves, Pecos, Brewster, and Presidio counties, between Lat. 31° 10′ and 29° 10′ N., and Long. 102° 40′ and 104° 30′ N.

The geology of Terrell County by D. D. Christner and O. C. Wheeler: Univ. of Texas Bull. No. 1819, Bur. Econ. Geol. and Technol., pp. 57, 8 pls., 1918. Sketch geological map on a scale of about 1 inch to 7.5 miles.

Notes on the geology and the oil possibilities of the northern Diablo Plateau in Texas by J. W. Beede: Univ. of Texas Bull. No. 1852, Bur. Econ. Geol. and Technol., 40 pp., 7 pls., 1918. Plate 1 is a colored geological map on a scale of about one inch to 3.25 miles.

[4] O'Hara, Cleophas C., A bibliography of the geology and mining interests of the Black Hills region: South Dakota School of Mines, Dept. of Geol., Bull no. 11, pp. 216-17, with a black and white base map, 1917

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The University of Texas has also published a bulletin on the geology of Val Verde County, a small part of which lies west of Pecos River.

These maps taken in connection with the El Paso and Van Horn folios, the other maps listed[5] below, and a considerable body of general geological literature, not listed here, give a fairly good idea of the larger geological features of the mountainous part of west Texas. It may appropriately be added that the United States Geological Survey has published many topographic maps of the region.

New Mexico. Darton, N. H., Red beds in New Mexico: U. S. Geol. Survey Prof. Paper, in preparation, estimated date of publication, 1922. Contains map of State, scale 12 miles = 1 inch.

Utah. Butler, B. S., Loughlin, G. F., Heikes, V. C., and others: U. S. Geol. Survey Prof. Paper 111, 1920, scale 12 miles to the inch.

Arizona. Darton, N. H., Field work in progress on map of State in coöperation with State of Arizona.

Idaho. Thomson, Francis A., Director of Bureau of Mines and Geology, Moscow, Idaho, has in course of preparation map of State: status unknown.

Nevada. No compilation started.

Washington. Most of the State of Washington has been geologically mapped, at least in a preliminary way. Those areas mapped by the United States Geological Survey are indicated in figure 1. The Washington Geological Survey has issued a volume[6] that is accompanied by colored geological maps for most of that part of Washington west of longitude 121° 30′ W. There is a general map on a scale of 7.5 miles to the inch, and there are other maps with the following titles and scales: Plate 3, Areal and structural map of southwestern Washington,

[5] Udden, J. A., A sketch of the geology of the Chisos Country, Brewster County, Texas: Univ. of Texas Bull. No. 93, pp. 101, 1907. This report is accompanied by a colored geological map by Benj. F. Hill and J. A. Udden, entitled, "Geological map of a portion of west Texas showing parts of Brewster, Presidio, Jeff Davis, and El Paso counties and south of the Southern Pacific R. R.; scale, 1 in. = 5 miles, 1904.

Richardson, George Burr, Report on a reconnaissance in Trans-Pecos Texas north of the Texas and Pacific Railway: Univ. of Texas Bull. No. 9, pp. 118, 11 pls., 1904. Plate 1 is a colored geological map on a scale of about 18 mi. to 1 in. or 1:500,000.

[6] Weaver, Charles E., The Tertiary formations of western Washington, Washington Geol. Survey Bull. No. 18, 327 pp., 30 pls., 1916.

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scale 2 miles to the inch: plate 4 has on it four maps: A, General geologic and structural map of the western and northern margin of the Olympic Peninsula, scale 2 miles to the inch: B, Areal and structural geologic map of a belt extending across the Puget Sound Basin into the Cascade Mountains, scale 1 mile to the inch; C, Areal and structural geologic map of the Quimper Peninsula, scale 2 miles to the inch; D, Areal and structural geologic map of the Cathcart-Cherry Valley Region, scale 2 miles to the inch. Besides these maps in a pocket at the back of the volume, there are some black and white maps interleaved with the text. Plate 30, opposite page 250, is a structural geologic map of western Washington.

Oregon. There is no general geological map of the State.

California. Besides the maps of California already issued by United States Geological Survey, other maps published by other organizations, maps that have been finished but not yet published, and work in progress need mention. Prof. James Perrin Smith has filled a great want by compiling a general "Geological map of the State of California"[7] on a scale of 12 miles to 1 inch, about 10 kilometers to 13.5 millimeters, or about 1:750,000. Other maps deserving mention are as follows:

The Salton Sea region, Calif., by John S. Brown: U. S. Geol. Survey Water Supply Paper, in preparation. Contains reconnaissance geologic map. Scale 1:500,000.

Geology and ground waters of the western part of San Diego County, Calif., by A. J. Ellis: U. S. Geol. Survey Water Supply Paper 446, 1919. Preliminary geologic map of San Diego County, scale 1:250,000.

Geology and oil in Kern County, Calif., by W. A. English: U. S. Geol. Survey Bull. 721, 1921. With geological map and section of northwestern Kern County. Correlation chart showing variation of Vaqueros and Maricopa formation along strike. Index map of southwest California, showing area considered in report. Production diagram. Scale of geological map 1:125,000.

CENTRAL AMERICA

Very little geological cartography has been done in Central America since the publication of Bailey Willis's Index to the stratigraphy of North America in 1912. The only map of any particular significance is one of Panama Canal Zone by Donald

[7] Issued by the State Mining Bureau of California, 1916.

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F. MacDonald.[8] Doctor MacDonald has prepared a general reconnaissance geological map of the Republic of Panama on a scale of 12.5 miles to the inch, but it is still in manuscript.

WEST INDIES

Cuba. Virtually the only geological map of Cuba is the one entitled "Croquis geológico de la Isla de Cuba" by Manuel Fernandez de Castro, supplemented by Pedro Salterain y Llegara,[9] 1869-1883, scale 1:2,000,000.

This is a rough sketch map and is erroneous in many particulars, but still it indicates some of the broader geological features of the island. The geological map of Cuba published as part of the Geological Map of North America compiled by Willis and Stose, was based upon the map of Fernandez de Castro and Salterain, somewhat revised by A. C. Spencer and myself; the same map with some alterations was republished by Pablo Ortega in 1918.[10] There is great need for a new geological map of Cuba and much information, in my possession and other information obtainable from geologists who have been engaged in commercial work there, is available for constructing such a map, but the preparation of the map would be a task of considerable magnitude. It is very desirable that there should be a well conducted geological survey of Cuba and it is hoped that provisions may be made for one in the near future.

Island of Haiti. Recently a preliminary geological survey of the Republic of Haiti has been made for the government of that Republic under the direction of the United States Geological Survey and the results of the field work are now being prepared for publication. The authors of the report and maps are Wendell P. Woodring, John S. Brown, and Wilbur S. Burbank. There will be a general geological map on a scale of about 1:400,000 and a few more detailed maps on a scale of 1:200,000.

[8] MacDonald, Donald F., Some engineering problems of the Panama Canal in their relation to geology and topography: U. S. Bur. Mines Bull. 86, pp. 88, 29 pls., 9 figs., 1915. Plate 4 is a generalized geologic map of the Canal Zone, in colors, scale 5 kms. to 13 mm., about 1:385,000. Republished as plate 153 in an article by McDonald: The sedimentary formations of the Panama Canal Zone with special reference to the stratigraphic relations of the fossiliferous beds: U. S. Nat. Mus. Bull. 103, pp. 525-545, pls. 153-154, 1919.

[9] Com. Mapa Espana Bol. vol. 8, p. G, 1881. The map was probably issued in 1883 or later for the dates "1869-83" are given on it, although it accompanies Com. Mapa Espana Bol. 1 vol. u, and the volume is dated 1881.

[10] Repub. Cuba, Direccion de Montes y Minas, Habana, 1918.

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A reconnaissance geological report[11] on the Dominican Republic contains a geological sketch map on a scale of about 1:695,000. This map, although admittedly crude, when taken in connection with the text of the report, gives a fair idea of the broader geological features of the Republic. Included in the volume is a larger scale map entitled "Geologic map of parts of the Provinces of Azua and Barahona," by D. D. Condit and C. P. Ross, scale 1:300,000.

Jamaica. The last issued geological map of Jamaica is the one by Hill.[12] This map "is compiled from map of Sawkins and Brown with additional data by Robert T. Hill," scale about 5.5 miles to 1 inch, approximately 1:350,000.

Porto Rico. Berkey[13] has recently twice published a geological reconnaissance map. This map has on it only the boundary between the Tertiary deposits and the older geological formations. Other maps of Porto Rico are one of San Juan district by D. R. Semmes[14] and one of the Coamo-Guayama district by E. T. Hodges.[15] Both of these maps are on a scale of 1:62,500. Maps of other areas are announced by the New York Academy of Sciences.

Virgin Islands. The Virgin Islands, except St. Croix, have been geologically mapped only in a very rough way. However, the maps published by Cleve are valuable. Plate 2 of the paper by Cleve[16] referred to above comprises a black and white map of a part of the Virgin Islands from Savana Island at the west end of St. Thomas to Virgin Gorda, on a scale of about 1 nautical

[11] Vaughan, T. W., Cooke, C. W., Condit, D. D., Ross, C. P., Woodring, W P., and Calkins, F. C., A geological reconnaissance of the Dominican Republic: Dom. Repub. Geol. Survey memoirs, vol. 1, 23 pls., Washington, 1921. (In press.)

[12] Hill, Robert T., The geology and physical geography of Jamaica: Study of a type of Antillean development: Harvard Coll. Mus. Comp. Zool. Bull. vol. 34, 256 pp., pls. 41, 1899, Plate 2, Geologic map.

[13] Berkey, Charles P., Geological reconnaissance of Porto Rico: New York Acad. Sci. Ann. vol. 25, pp. 1-70, 3 pls., 1915. Plate 2, geological map, scale 10 km. to 17.5 mm.

Berkey, Charles P., Geological introduction: New York Acad. Sci. Survey Porto Rico and Virgin Ids., vol. 1, pt. 1, pp. 11-29, 1 map, 1919.

[14] Semmes, D. R., Geology of the San Juan district: New York Acad. Sci. Porto Rico and Virgin Islands, vol. 1, pt. 1, pp. 35-110, 4 pls., 1 colored geological map, 1919.

[15] Hodges, E. T., Geology of the Coamo-Guayama district: Ibid., vol 1, part 2, pp. 111-228, colored geological map, 1920.

[16] Cleve, P. T., On the geology of the northeastern West India Islands: Kongl. Svenska Vet.-Akad. Handl., vol. 9, No. 12, pp. 48, 2 pls. (maps), 1871.

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mile to 7.5 mm., about 17 nautical miles to 5 in. = 3.4 nautical miles to 1 inch, about 1:147,000, and a geological map of St. Croix on a scale of 1:232,000. John Quin[17] has published a map of St. Croix on a scale of about 10° of latitude to 6 inches, 10 nautical miles to 6 inches. In May and June, 1919, I had an opportunity to make a geological reconnaissance of Vieques, Culebra, St. Thomas, St. John, and St. Croix and have published an abstract of some of the scientific results of my examinations[18] but have not yet had an opportunity to complete maps presenting the additional information obtained on areal geology.

LESSER ANTILLES EAST AND SOUTH OF ANEGADA PASSAGE

It is generally known that the main Caribbean arc of islands splits north of Guadaloupe. The eastern part of Guadaloupe is composed mostly of sedimentary rocks, and north of it the islands of the outer fork of the island-arc are composed either of sediments or of volcanic and sedimentary rocks. The islands of the main Caribbean arc and its inner (western) prong north of Guadaloupe are entirely composed of volcanic rocks or of volcanic rocks with patches of sediments, mostly limestone, overlying them. The volcanic islands are Saba, St. Eustatius, St. Christopher, Nevis, Redonda, Montserrat, the western half of Guadaloupe, Dominica, Martinique (small areas of sediments), St. Vincent, the Grenadines, and Grenada. Special geological maps of most of these islands have not been made because of lack of diversity in lithology but the geological features are rather well known and there is a considerable literature on them. There is more need for special maps of the islands composed of sediments or of sediments and volcanic rocks, and there are either geological maps of most of them or data are available for such maps. The following are notes on geological maps of the Lesser Antilles:

One of the important works on the West Indian islands north of and including Guadaloupe is the paper by Cleve already cited. Plate 1 of it is a geological map of the northeastern West Indies on a scale of 1:1,751,000. On Plate 2 is a

[17] Quin, John, The building of an island, being a sketch of the geological structure of the Danish West Indian Island of St. Croix, or Santa Cruz: 106 pp., unnumbered pls., 1907. Published by the author in Christiansted, St. Croix; printed by Chauncey Holt in New York.

[18] Vaughan, T. W., Stratigraphy of the Virgin Islands of the United States and of Culebra and Vieques Islands: Geol. Soc. of Amer. Bull., vol. 31, pp. 216-217, 1920.

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geological map of St. Bartholomew on a much larger scale, which is not given. In the text on page 23 there is a sketch geological map of the Dutch part of St. Martin, scale not given.

Anguilla. Cleve in his map mentioned above represents all of Anguilla as Miocene limestone, but he mentions in his text that this formation is underlain by trappean rock. For later notes on Anguilla see reference given below.[19]

St. Martin. Molengraaff[20] has published a sketch map on a scale of 1 30,000.

St. Eustatius. Molengraaff has also published a geological map of this small island,[21] scale 1:56,700.

Antigua. The best geological map of Antigua is still that of Purves,[22] which is on a scale of 2.5 English miles to 1 inch. J. W. Spencer[23] has published a more generalized map on a scale of 2 miles to 1 3/16 of an inch; and R. J. L. Guppy[24] has published a sketch map of the island on a scale of 6 miles to 1 inch.

Martinique. An article by Giraud[25] is accompanied by a geological map on a scale of 1:80,000.

Barbados. Geologists are indebted to J. B. Harrison and A. J. Jukes-Browne[26] for probably the best geological map of any West Indian island. Their geological map of Barbados is on a scale of 1 1/3 inches to a mile or 1 inch to 3960 feet. Certain features of this map are more or less modified in two

[19] Vaughan, T. W., U. S. Nat. Mus. Bull. 103, pp. 209, 262, 1919.

[20] Molengraaff, G. A. F., Het geologisch verband tuschen de West-Indische Eilanden: 1e Nat. en. Geneeskund. Cong. Amsterdam, 1887, Handel., 10 pp., 1 map.

[21] Molengraaff, G. A. F., De geologie van het eiland St. Eustatius [doctor's thesis]: pp. 64+4, 3 pls., and frontispiece, E. J. Brill, Leiden, 1886.

[22] Purves, J. C., Esquisse géologique de l'ile d'Antigoa: Belgique Mus. Roy. Bull., vol. 3, pp. 273-318, pl. 14, 1884.

[23] Spencer, J. W., On the geological and physical development of Antigua: Geol. Soc. London Quart. Jour., vol. 57, pp. 490-495, pl. 15 (map), 1901.

[24] Guppy, R. J. L., On the geology of Antigua and other West Indian Islands with reference to the physical history of the Caribbean region: Geol. Soc. London Quart. Jour., vol. 57, pp. 681-700, plate 50 (map), 1901. Geological sketch map of Antigua on p. 683.

[25] Giraud, Jean, Esquisse géologique de la Martinique avec carte géologique: 60 pp., table des matières, légende de la carte et des coupes, 1 p. of sections, colored geological map.

[26] Harrison, J. B., and Jukes-Browne, A. J., The geology of Barbados, being an explanation of the geological map of Barbados prepared by the same authors: 64 pp., 1890. Published by authority of the Barbadian legislature.

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subsequent publications.[27] Cunningham Craig has published a number of sketch maps of parts of Barbados to illustrate his investigations into the possibility of the occurrence of petroleum there and they are of value in the study of the structure of the older rocks, but they do not add materially to the knowledge of the areal geology.

SOME ISLANDS OFF THE SOUTH AMERICAN COAST

Trinidad. Although Trinidad is more properly classifiable with South America than with the West Indies it will be mentioned. There is only one general geological map of the island known to me, the one that accompanied the report by Walls and Sawkins,[28] on a scale of 1 inch to 4 miles. This map does credit to the authors but naturally needs revision after more than 60 years. E. H. Cunningham Craig has published a number of maps in his reports on the oil-fields of Trinidad,[29] but the data on them can scarcely be transferred to the usual geological map as the information needed for age determinations is not given.

Curaçao, Arube, and Bonaire. These islands are also South American in their affinities. Martin[30] has published geological maps of each of them as follows: Curaçao, scale 1:150,000; Arube, scale 1:100,000; Bonaire, scale 1:150,000.

[27] Franks, G. F., and Harrison, J. B., The Globigerina-marls and basal reef-rocks: Geol. Soc. London Quart. Jour., vol 54, pp. 540-550, 1898. See sketch map on p. 542, scale 4 in. to 1 mi.

Harrison, J. B., The coral-rocks of Barbados: Ibid., vol. 63, pp. 318-337, pl. 23 (map and section), 1907. Map scale 1 in. to 1 mi.

[28] Wall, G. P., and Sawkins, J. G., Report on the geology of Trinidad: 211 pp., 5 sheets of maps and sections, frontispiece, and 58 text-figs., 1860, London: Printed for her Majesty's stationery office: Published by Longman, Green, Longman, and Roberts.

[29] Reports of the Government Geologist, 1905-1907.

[30] Martin, K., Geologische Studien ueber Niederlaendisch West-Indien, auf Grund eigener Untersuchungsreisen: 238 pp., 4 col. maps, 4 pls., 41 woodcuts, E. J. Brill, Leiden, 1888.

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INFORME SOBRE MAPAS GEOLÓGICOS DE MEXICO

By L. Salazar Salinas, Director del Instituto Geológico, Mexico

Los mapas geológicos de la República Mexicana han sido hechos utilizando estudios y levantamientos geológicos de diferente naturaleza, tomando como base planos topográficos de grados distintos de exactitud y detalle y se han formado con diversos fines. Estos mapas, por lo tanto, son muy variados, abarcan extensiones—superficiales también muy variadas y son más o menos exactos, según la calidad de los planos topográficos usados y según los usos a que se han destinado.

Pueden dividirse, no obstante esta falta de uniformidad, en los cuatro grupos siguientes:

1. Mapas geológicos generales;
2. Mapas geológicos locales;
3. Cortes geológicos;
4. Mapas especiales.

Los planos pertenecientes a los tres primeros grupos han sido hechos por elementos oficiales (Instituto Geológico, Comisiones del Gobierno, etc.) en tanto que los del último grupo son debidos a diversas compañías y negociaciones o peritos particulares.

La mayoría de los mapas geológicos generales abarcan zonas extensas y los datos que se han aprovechado en su dibujo, se han obtenido por reconocimientos generales, recorriendo itinerarios geológicos entre las poblaciones principales de los Estados que forman la República, o entre los puntos más notables de su relievo topográfico o siguiendo vías férreas, caminos nacionales o vecinales, veredas, etc.; estos mapas abarcan extensiones superficiales de contornos muy irregulares, pues no se ha adoptado el método seguido en el Servicio Geológico de los Estados Unidos del Norte de limitar las zonas reconocidas por paralelos y cuarternario; las principales masas de rocas intrusivas y todas principio se siguieron itinerarios geológicos en los Estados de Durango, Sonora, Sinaloa, Zacatecas, Jalisco, Querétaro, Hidalgo, Puebla, Oaxaca y Guerrero y posteriormente se han recorrido otros itinerarios en los demás Estados y Territorios de la Federación. Los datos geológicos obtenidos con este sistema de itinerarios se han utilizado para la formación de la Carta Geológica General de la República, en la que han podido delinearse a grandes rasgos los límites de las formaciones perteneci-

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entes al arcaico, carbónico, triásico, jurásico, cretácico, terciario y cuarternario; las principales masas de rocas intrusivas y todas las rocas ígneas (generalmente terciarias) del país. De la Carta Geológica General se han hecho cuatro ediciones: la primera en 1891 y las tres siguientes en 1907, 1908 y 1911 sucesivamente. El sistema de itinerarios geológicos se ha tenido que adoptar para la formación de estos mapas generales en vista de la gran extensión territorial de la República, de los escasos elementos con que se cuenta en muchas de las porciones despobladas de su territorio y en vista también del reducido personal con que desde un principio ha contado el Servicio Geológico Mexicano. Teniendo en cuenta estas circunstancias este sistema de itinerarios geológicos, tendrá que seguirse todavía por algún tiempo para la formación de esta clase de mapas.

Los mapas geológicos locales han abarcado, por lo general, zonas muy reducidas pero se han hecho utilizando planos exactos y muy detallados, levantados por miembros de la sección de topografía del Instituto Geológico; estos mapas han sido el resultado de estudios cuidadosos de geólogos especialistas del citado Instituto y se ha procurado comprender en ellos zonas alrededor de los centros industriales de importancia (mineros, petroleros, etc.) o de gran interés paleontológico para el estudio de la estratigrafía del país. No encuentran publicados en la serie de Boletines, Parergones, Anales, etc. del Instituto Geológico.

Los cortes geológicos han tenido por objeto fijar la estructura general del país y establecer las relaciones mutuas deposición de las principales formaciones geológicas de México. Muchos de estos cortes han seguido las vías férreas o los caminos nacionales y entre ellos es digno de mencionarse el corte geológico entre Acapulco y Veracruz, hecho según la línea que une a estos dos importantes puertos, el cual corte abarca una faja de un kilómetro a uno y otro lado de esta línea, y que está aún inédito.

De los mapas especiales pueden decirse que han sido hechos para fines muy particulares por negociaciones mineras, compañías petroleras, o peritos diversos. De estos estudios se han dado a conocer algunos pocos mapas geológicos que existen dispersos en publicaciones de índole muy diversa, permaneciendo la mayor parte en poder de las negociaciones o compañías para su uso particular.

En la Carta de la República que acompaña a este Informe se indica con color las extensiones abarcadas por los mapas geoló-

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gicos levantados hasta la fecha y con diferentes colores se distinguen los objetos con que han sido hechos o asuntos de que tratan; así como los principales perfiles geológicos a los que se ha hecho referencia.

Se acompaña además los siguientes mapas geológicos de la República (edición de 1911):

Una carta topográfica del relieve de la República Mexicana.

Plano que muestra las relaciones del vulcanismo y la tectónica con dicho relieve.

Una carta de las regiones auríferas, auro-argentíferas, cupríferas, plumbíferos y ferríferos de México.

A continuación se incluye una lista de la mayor parte de las publicaciones oficiales en las que existen mapas geológicos de México.

BOLETINES INSTITUTO GEOLOGICO DE MEXICO

3. Sapper, Carlos (1896). Mapa geológico de los Estados Chiapas y Tabasco, escala, 1: 1,000,000.

Sapper, Carlos, Bosque jo de una carta geológica de la Peninsula de Yucatan, escala, 1:1,000,000.

4, 5, 6, Del Castillo (1897). (Bosquejo Geológico de Mexico.) Corte geológico de San Andres por Tijera y Sianon a Copalquin, Estado de Durango.

Del Castillo, Corte geológico de Guanacevi a Rancho Blanco, Estado de Durango, escalas: horizontal, 1:400,000; vertical, 1:20,000.

Del Castillo, Perfil de Manzanillo a Zapotlan, escalas: horizontal, 1:1,000,000; vertical, 1.25,000.

Del Castillo, Perfil de Nochistlán a San Blas, escales; horizontal, 1:1,000,000; vertical, 1:50,000.

Del Castillo, Perfil de Autlan a Guadalajara, escales: Horizontal, 1:500,000 vertical, 1:25,000.

Munoz, Lumbier, Corte geológico de Agiabampo a Chihuahua, con la proyección de los principales minerales de la Sierra Madre, escales; horizontal, 1:400,000; vertical, 1:50,000.

10. Waitz, P., y Urbina, F., (1898) Mapa los temblores de Quadalajara en 1912, escala: 1:200,000.

16. Villarello, J. D. (1902). Regiones petrolíferas de San Jose de las Rusias, Sabino y Tancasnequi, escala, 1:100,000.

Villarello, J. D., Regiones petrolíferas de Aquismon, Ebano, Tantoyuca, Tuxpan y Panpantla, escala, 1:100,000.

Villarello, J. D., Región petrolífera del Istmo de Tehuantepec, escala, 1:800,000.

20. Böse, E. (1905). Carta geológica de los Estados de Chipas y Tabasco, escala, 1:1,000,000.

Böse, E., Corte geológico del Istmo de Tehuantepec, escala: horizontal, 1:500,000; vertical, 1:100,000.

25. Böse, E. (1910). Carta géologique du Cerro de Muleros, escala, 1:10,000.

28. Villarello, J. D. (1911). Croquis geológico del borde meridional de la Cuenca de México, escala, 1:100,000.

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32. Urbina, F., and Camacho, H. (1913). Croquis de la región megaséismica del Estado de Mexico conmovida el 19 de Noviembre de 1912.

35. Del Castillo (1918). Perfil de México a El Paso del Norte, escala: horizontal, 1:4,000,000; vertical, 1:50,000.
Del Castillo, Perfil del Camino de San Blas a Veracruz, escala: horizontal, 1:4,000,000; vertical, 1:50,000.
Del Castillo, Perfil del Camino de Toluca a Los Placeros, escala: horizontal, 1:1,000,000; vertical, 1:50,000.

37. T. Flores, Plano geológico de los distritos mineros de El Oro y Tlalpujahua.
T. Flores, Croquis topográfico y geológico de la zona minera comprendida entre los Minerales de El Chico y Zimapán, Estrado de Hidalgo. (En prensa.)

PARERGONES INSTITUTO GEOLÓGICO DE MEXICO

I. Böse, E., Los temblores de Zanatepec: escala, 1:5,000,000, Tomo 1, No. 1, 1903.
Angermann, E., Geológia e hidrología de los alrededores de la Paz, B. C.: escala, 1:50,000, Tomo 1, No. 2, 1904.
Angermann, E., Apuntes sobre el paleozoico en Sonora: escala, 1:1,000,000, Tomo 1, No. 3, 1904.
Villabello, J. D., Estudio de la hidrología interna de los alrededores de Cadereyta Méndez, Estado de Queretaro: escala, 1:200,000, Tomo 1, No. 6, 1904.
Villabello, J. D., Estudio de la Hidrología subterránea de los alrededores de Querétaro: escala, 1:200,000, Tomo 1, No. 8, 1905.
Ordonez, E., Los Xalapazcos del Estado de Puebla: Plano geológicos de la Sierra de Techachalco y de los Axalapazcos, escala, 1:40,000, Tomo 1, Nos. 9 y 10, 1905 y 1906.

II. Angermann, E., Mapa geológico de los alrededores de San Pedro del Gallo, Partido de Nazas, Durango, escala, 1:100,000, Tomo 2, No. 1, 1907.
Angermann, E., Plano geológico del Mineral de Penoles, escala, 1:50,000, Tomo 2, No. 1, 1907.
Angermann, E., Perfil de Colima a Paso del Rio, escala: horizontal, 1:250,000; vertical, 1:2,500, Tomo 2, No. 1, 1907.
Villafana, A., Plano geológico de la región volcánica de Jorullo, escala, 1:40,000, Tomo 2, No. 3, 1907.
Böse, E., Villafana, A., Garcia, J., y Garcia, El Temblor del 14 de Abril de 1907: escala, 1:1,000,000, Tomo 2, Nos. 4, 5 y 6, 1908.
Villafana, A., Fuente termal en Cuitzeo de Abasolo, Estado de Guanajuato: Croquis geológico, escala, 1:25,000, Tomo 2, No. 7, 1908.
Paredes, T., Croquis geológico de la región de Río Verde, San Luis Potosi y Arroyo Seco, Qro., escala, 1:200,000, Tomo 2, No. 8, 1909.
Flores, T., Croquis de los alrededores de Tetecala, Estado de Morelos, escala, 1:85,000, Tomo 2, No. 9, 1909.

III. Villarello, J. D., El Pozo de Petróleo de Dos Bocas, Estado de Veracruz, escala, 1:1,000,000, Tomo 3, No. 1, 1909.
Burckhardt, C., and Villarello, J. D., Croquis geológico de los aldrededores del Río Nazas entre las Tetillas y la presa del Refugio, escala, 1:80,000, Tomo 3, No. 2, 1909.
Paredes, T., Estudio hidrológico del Valle de Ixmiquilpan. Croquis geológico y topográfico, escala; horizontal, 1:200,000; vertical, 1:100,000, Tomo 3, No. 3, 1909.

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Villarello, J. D., Plano geológico de la Comarca Lagunera de Tlahualilo, escala, 1:200,000, Tomo 3, No. 4, 1910.
Burckhardt, C., Plano geológico de la región de San Pedro del Gallo, escala, 1:25,000, Tomo 3, No. 6, 1910.

V. Villarello, J. D., Croquis de la hidrológia subterránea del Estado de Coahuila, escala: 1:1,000,000, Vol. 5, No. 5, 1913.

PALEONTOLÓGICO

Aguilera, J. G., Carte géologique de la Sierra entre Tehuscán et San Juan Raya, Estado de Puebla, escala, 1:50,000.
Ordonez, E., Coupe géologique de Acámbaro a Uruapam, F. N. de México, escala: horizontal, 1:1,000,000; vertical, 1:25 000.
Villarello, J. D., Flores, T., y Robles, R., Carte géologique du District minero de Guanajuato, escala, 1:25,000.
Böse, E., Carte géologique du Cerro de Muleros, escala, 1:50,000.
Böse, E., Carte géologique des environs de Parras, Coahuila, escala, 1:25,000.
Burckhardt, C., Carte géologique des Sierras de Mazapil y Santa Rosa, escala, 1:50,000.
Böse, E., Profile géologique de la Sierra Madre Oriental le long du Chemin de fer-"Mexicano" entre Rio Metlac et Roca del Monte, escala, 1:50,000, G. d. e. d. x. C. G. I.
Ordonez, E., Profil géologique de Tomellin a Oaxaca, escala: vertical, 1:300,000; horizontal, 1:25,000.
Böse, E., Profils géologique le long de Chemin de fer entre Soledad y los Muertos (Saltillo a Monterrey), escala, 1:50,000.
Böse, E., Profil géologique transversal de l'Ithme de Tehuantepec, escala: horizontal 1:500,000; vertical, 1:100,000.

ANALES INSTITUTO GEOLÓGICO DE MEXICO

4. Camacho, H., Plano de Jacala y sus alrededores, escala, 1:8,000.
8. Camacho, H. (1920). Las aguas subterráneas en Tlanalapan, Dto. de Apam, Estado de Hidalgo, escala, 1:100,000.
Camacho, H., Informe acerca de las aguas subterráneas del valle de Tecamachalco o Valsequillo, Estado de Puebla.

BOLETINES DE LA SOCIEDAD GEOLÓGICA MEXICANA

1. Flores, T., Croquis geológico de los minerales de Providensia y San Juan de la Chica (Gto.), escala, 1:20,000.
3. Carranco, A., La región minera de Trinidad y Anexas, escala, 1:6 000.
5. Villarello, J. D., Croquis geológico de los alrededores de Montenegro (Qro.), escala, 1:200,000.
Flores, T., Croquis geológico de la región explorada a través de las cuencas de los rios Mixteco y Penoles (Oax.), escala, 1:725 000.
7. Burrows, R. H., Approximate geology of a portion of Eastern Chihuahua, escala, 1:1,000,000.
Roldan, L. Villar, Croquis geológico y minero del Mineral de "El Oro," Durango (sin escala).
8. Waitz, P. y Rijar, L., y Haro, Perfiles geológicos de la Sierra de la Yesca y alrededores, escalas: 1:20,000; 1:50,000; 1:22,000.

DIVERSOS

Fr. Weidner, Croquis geológico del Estado de Sinaloa, escala, 1:1,500,000. Petermann, Geog. Mittei., Tomo 30, 1884.

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Eisen, G., and Vaslit, F. H., Geological map of the cape region of Baja California. (Sin escala.) Proc. California Acad. Sci., 2nd Series, Vol. V., 1895.
Lindgren, W., Notes on the geology of Baja California, Mexico. Proc. California Acad. Sci., 2nd Series, Vol. V., 1895.
Waitz, P., Carte géologique et Miniere des environs de Parral, escala, 1:50,000, Geológico-minero.

CATALOG OF GEOLOGICAL MAPS OF SOUTH AMERICA

BY H. B. SULLIVAN, United States Geological Survey

This catalog of maps, prepared at the request of T. Wayland Vaughan is listed for publication by the American Geographical Society, New York.

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CORRELATIONS OF POST-CRETACEOUS FORMATIONS IN THE PACIFIC REGION

CORRELATION OF THE LATER MESOZOIC AND CENOZOIC FORMATIONS OF NEW ZEALAND

By T. Wayland Vaughan

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Introduction

At the time this series of papers on the correlation of the later, especially the Tertiary, geological formation in the Pacific region was planned in Honolulu, Dr. J. Allan Thomson was asked to prepare one on New Zealand but illness prevented his compliance with the request. It is obvious that it is necessary to have a statement on New Zealand in order to make this discussion complete, because New Zealand is both an area in which there are many fossils and one that exemplifies the difficulties of making geological correlations with other parts of the world in an isolated region of the Pacific. As no one else was available for the task I have with much trepidation

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undertaken to write a statement, which I trust will give some idea of the problems with which the New Zealand geologist must deal and of what has been done toward the solution of them.

GENERAL GEOLOGICAL FEATURES

General accounts of the geology of New Zealand have recently been published in book form by Park (1910, 2[1]), Marshall (1911, 1, 1912, 2[1]), and F. R. C. Reed (1921[1]), and Cotton has published two useful short articles on the subject (1913, 2, 1916, 4). I have found the last cited article by Cotton especially helpful.

In the geological history of New Zealand there are two well-marked periods of major diastrophism and these accordingly divide the rocks of the islands into three major categories. The first period of diastrophism occurred in late Jurassic or very early Cretaceous time and is termed by Cotton (1916, 4, p. 243) the "Mesozoic orogenic period"; the second period occurred at the close of the Tertiary deposition and is termed by Cotton (Idem, p. 248) the "Kaikoura orogenic period."

The geological ages of the rocks that are older than the Mesozoic orogenic period are in some doubt and are the subject of divergent opinions. According to Marshall (1911, 1) they may be divided into the Manapouri system, probably of Archaean age; the Aorere System, of Ordivician age; the Baton River System, supposed to be of Siluro-Devonian age; and the Maitai System, which probably includes rocks that range in age from Permo-Carboniferous to Jurassic. The Maitai system according to Marshall includes rocks of Trias-Jura age, but he includes in it the Te Anau and the Hokonui systems of Park. Park (1910, 2) correlates his Te Anau system with the Carboniferous and his Hokonui system with Permian to Jurassic. Mention is made of these discrepant classifications to indicate the uncertain state of knowledge of some of the older formations of New Zealand. The point of importance in this connection is the age of the youngest rocks involved in the Mesozoic orogenic movements. It appears to be Jurassic (Park, 1910, 2, pp. 75-81; Marshall, 1911, 1, p. 39). The date of the deformation would therefore be late Jurassic or early Cretaceous.

[1] See bibliography at the end of this paper for full references.

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After this period of diastrophism the rocks were subjected to long continued erosion and the land surface was reduced either to or almost to a peneplain (Speight, 1915, **2**; Cotton, 1916, **4**; 1916, **5**; 1917, **6**; Thomson, 1920, **15**, p. 340). This period of elevation was followed by one of depression in about middle Cretaceous time and the sea, with some halts and oscillations in the position of the strand gradually overflowed most of, if not all of, the former land areas, and then withdrew. It was during this period of inundation that the rocks particularly considered in this paper were deposited. These rocks have been designated "covering strata" (Cotton, 1913, **2**, p. 246; 1916, **4**, pp. 247 *et seq.*) *or* "marginal" (Thomson, 1913, **4**, p. 16). These are the deposits that Park (1910, **2**) classified under his Amuri, Karamea, and Wanganui systems; that Marshall first (1911, **1**) classified in the Oamaru and Wanganui systems, which he later (1919, **12**) combined into his Oamaru system; and that Thomson classified under his Notocene. The time of the deposition of these rocks was one of relative crustal stability until near the end when a peculiar formation, the Great Marlborough conglomerate, gave evidence of accumulating earth strains and at least local deformation (Cotton, 1914, **4**). Further evidence of unrest is indicated by a reported probable unconformity between the uppermost Mt. Brown beds with 34 per cent of Recent species and the Greta beds with 67 per cent of Recent species (Thomson, 1920, **15**, p. 397).

The deposition of this category of rocks was terminated by the Kaikoura orogeny. Cotton says (1916, **4**, p. 314):

> Brief reference may here be made to the effects of the Kaikoura movements, though anything like a complete account of the structure and surface forms produced cannot be attempted. In Marlborough the great reverse faults, first noted by McKay, and the huge tilted and compressed blocks from which the Kaikoura ranges have been carved are most impressive. Though less intense the effects in North Canterbury are similar in kind, and a geological map of the district would present the appearance of a mosaic of "older mass" and "covering strata" formations as a result of block faulting, with the preservation of the latter on the lower blocks and their removal by erosion from the higher.

The destruction of the "covering strata" from areas of high stand and their preservation in those in depressions is well illustrated in the Middle Clarence Valley (Cotton, 1913, **2**, p. 227; Thomson, 1919, **14**, p. 300), where the covering strata have been entirely removed except at the foot of an up-thrown

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fault block. The earth movements during the Kaikoura orogenic period and subsequent erosion have profoundly affected the distribution of the outcrops of the "covering," although in general Marshall, Speight, and Cotton (1911, p. 380) are correct in their statement that "In all but a very few of the areas where the series is exposed the stratification is simple. In many cases the strata lie flat; but where they border on an older series of rocks they are generally inclined and folded in some simple manner, though in some places it causes them to lie vertically."

Subsequent to the Kaikoura deformation parts of New Zealand have been subjected to uplift, parts to depression, and other parts to oscillation (Cotton, 1916, **4**, p. 318), in places causing very young marine deposits to emerge from the sea (Thomson, 1917, **11**). It is for this period of the history of New Zealand that Thomson proposed the term Notopleistocene (1916, **9**, p. 411). As this epoch is not the subject of discussion in the present paper no more remarks will be made upon it.

DIFFICULTIES IN MAKING CORRELATIONS OF THE YOUNGER GEOLOGICAL FORMATIONS OF NEW ZEALAND

The obstacles in the way of making geological correlations in New Zealand are virtually the same as those encountered in Java and so well summarized by Martin in his paper, a translation of which is given in subsequent pages of this report. Marshall and Thomson have recognized and have expressed these difficulties and have tried to direct their researches so as to overcome them. I shall analyze the subject in my own way, but I shall say nothing of which Marshall and Thomson are not cognizant. The difficulties may be listed as follows: disconnected outcrops; uncertainty regarding the stratigraphy in the different areas of outcrop; inadequate paleontologic knowledge; incomplete knowledge of the living faunas; absence of a biologically characterized standard for comparison. Each of these topics will be briefly discussed.

DISCONNECTED OUTCROPS

The map herewith reproduced, figure 1, is taken from Marshall, Speight, and Cotton (1911) and Marshall (1916, **5**). It shows the principal areas of outcrop of the Cretaceous and

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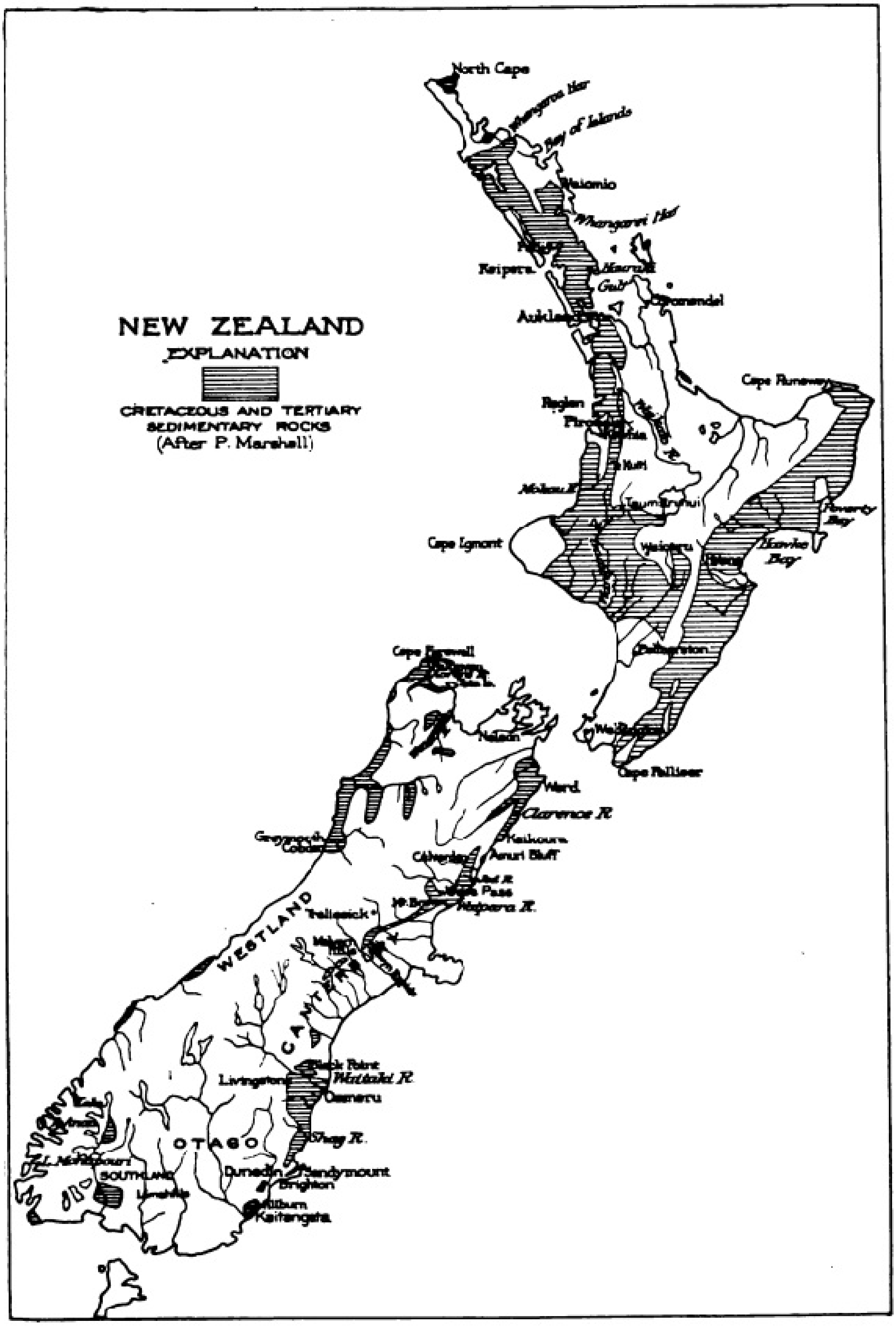


FIGURE I. Map of New Zealand showing principal areas of outcrops of Cretaceous and Tertiary rocks.

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Tertiary rocks in New Zealand. A glance at this map shows how in South Island there are on its east side disconnected outcrops between Kaitangata and Clarence River, with an outlier in Trelissick Basin. There are three areas indicated in Southland; and there are other disconnected areas on the west side of the Island. In North Island there are two main belts, one between Cape Runaway and Cape Palliser; the other between Wanganui and Whangaroa. But the relations are not so simple as the map indicates. Because of the lack of continuity in outcrop, it is not practicable to trace the geological formations throughout long distances. The difficulty is increased by the dissimilarity in the rocks in different areas. For example, the Middle Cretaceous Clarentian rocks have not been found below the Upper Cretaceous Piripauan. Thomson's contention for minor diastrophic provinces in New Zealand during the deposition of the Notocene rocks is well founded (1916, **9**; 1920, **15**, pp. 398-400). Furthermore it has been shown that some rocks of similar lithologic facies are not of the same age, for instance, the Kaitangatan Amuri limestone and the middle Oamurian Ototara limestone (Thomson, 1920, **15**, p. 399).

UNCERTAINTY REGARDING THE STRATIGRAPHY IN THE DIFFERENT AREAS OF OUTCROP

On following pages considerable attention is given to the discrepant views regarding the stratigraphic relations of the successive beds in areas in which the beds are exposed. There has been controversy in New Zealand over the presence or absence of unconformities or disconformities in the different sections for years, and, although, a great deal of field work has been done on the problem agreement has not yet been attained among the different students of it.

INADEQUATE PALEONTOLOGICAL KNOWLEDGE

Although the titles of 52 papers in the bibliography at the end of this paper are marked with an asterisk (*) to indicate their paleontological nature, and no references are given to the earlier work of Gray, Mantell, Forbes, Huxley, Rupert Jones, Zittel, Karrer, Stolicka, Stache, Jaeger, Hector, Hutton, E. T. Newton, H. Woodward, Tate, Tenison-Wood, Vine, Kirk, von Ettinghausen, Waters, Davis, Lydekker, Hinde and Holmes, Benham, Boehm, Hamilton, Lemoine and R.

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Douvillé, and Bather, and to earlier papers by authors whose names appear in the bibliography, it is still true that critical knowledge of the paleontology of most New Zealand geological formations is inadequate. This is recognized by both Marshall and Thomson, and both of them have labored assiduously to remedy the deficiencies in information. It is only recently that attempts have been made mainly by Marshall, Thomson, and Suter to ascertain what fossils occur in each bed within each distinctive area. Although there has been most gratifying progress much remains to be done, and New Zealand malacology and paleontology has sustained in the death of Mr. Suter a heavy loss that may for some time affect the progress of paleontology there.

It is true in New Zealand, as in other parts of the world, that some formations that occupy critical positions in the sections have not yielded determinable fossils. The Amuri limestone is such a formation. Thomson has found in its upper part, within 10 feet of its top, an Oamaruian mulluscan fauna, of which 19 per cent are Recent (1916, **8**, p. 51), but it is still unknown what may be the age of the base of the formation, the maximum thickness of which is estimated to be 2750 feet (Thomson, 1916, **8**, p. 53.)

INCOMPLETE KNOWLEDGE OF THE LIVING FAUNAS

Suter has rendered science a great service in the publication of his Manual of New Zealand Mollusca (Suter, 1913, **2**), but this work is mostly devoted to the shoal water fauna. Some one might do a useful piece of work by tabulating, according to depth and nature of the bottom the species considered in this volume. The deeper water mollusca also need study. And, for geological purposes, all organisms that might be preserved as fossils are worthy of detailed investigation, *viz.*, foraminifera, corals, echinoids, bryozoa, brachiopods, crustaceans, and pelagic mammals.

ABSENCE OF A BIOLOGICALLY CHARACTERIZED STANDARD FOR COMPARISON

The isolation of the Pacific Ocean from the Atlantic is specially discussed by Professor Martin in his article on Java, which forms one of this series of articles, and by me in my article on the basis of post-Cretaceous correlation in the Pacific

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region. The conection between the Pacific and Atlantic by way of Tethys appears to have been closed before latest Eocene time and perhaps except transitory communication there has been no connection between the two oceans since older Miocene time across Central America. Marshall's insistence on the isolation of the New Zealand fauna appears to me to be fully warranted, and I believe the following statement by him is correct (1918, 12, p. 277):

No one Tertiary horizon which has had its Mollusca properly collected and described shows any notable introduction of species or genera which are absent from lower horizons. Such facts go far to support the idea of a continuous isolation of New Zealand throughout Tertiary times —a contention that has been previously urged by the author on purely stratigraphical grounds. This position has lately been supported by Thomson and Morgan, though stated in a different manner: "Each Tertiary fauna seems to merge gradually into the succeeding one" [Suter, 1917, 4, p. V; Thomson, 1919, 13]. Mr. Suter also has written to me as follows: "There is no doubt that our molluscan fauna has greatly decreased, and also that the Tertiary forms gradually merge into one another."

The only two datum planes at the present time for correlating the New Zealand Tertiary horizons with horizons of other regions are the Upper Cretaceous Piripauan below and the Recent above. between these two planes correlation must be by interpolation, and at present this must be done, as both Marshall and Thomson have done, by the percentage of Recent forms.

Marshall discusses the difficulties and uncertainties in estimating the percentage of Recent species (1918, 12, p. 275) in the English equivalents of the words Professor Martin used in discussing the correlation of the Javan Tertiary formation in this volume, and on p. 276 (1918, 12) he says:

The isolation of New Zealand and the relatively rare arrival of species from outside the New Zealand area make it probable that species could survive for a much longer time here than on coast-lines where there was more competition from newly arrived species. It is probable that a fauna in New Zealand with 20 per cent of Recent species would have a much greater antiquity than a fauna with a similar percentage of Recent species in Europe or America.

Marshall also says in this paper (1918, 12, p. 277):

It is to be hoped that a complete comparison may be possible ere long between our Tertiary faunas and those of Australia, South America, and North America. In the meantime one can only emphasize the well-known fact that our Tertiary fauna closely resembles that of South America, where the species of Turritella, Malletia, Struthiolaria, Epi-

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tonium, and Polinices are evidently extremely closely related to ours. Again, the occurrence of the genera Perissolax and Heteroterma in the Wangaloa beds shows a rather unexpected relationship between our earliest Tertiary beds and those of the Tejon and Martinez districts in California.

MORE RECENT CLASSIFICATIONS OF THE LATER MESOZOIC AND TERTIARY FORMATIONS OF NEW ZEALAND

In this section the views of Park, Marshall, Thomson, and Morgan will be particularly discussed and mention will be made of some of Cotton's work.

VIEWS OF PARK

Park's (1910, 2, p. 25) classification and correlations are as follows:

Systems	Series	Probable age
Recent	River alluvium, drifting sand Beach sand and gravel	Recent
Pleistocene	Raised beaches Older gravel drifts Newer moraines Older moraines Boulder-clay and esker drifts	Pleistocene
	Unconformity	
Wanganui System	(a) Petane series (b) Waitotara series (c) Awatere series	Newer Pliocene Older Pliocene
	Unconformity	
Karamea System	(a) Oamaru series (b) Waimangaroa series	Miocene Eocene
	Unconformity	
Amuri System	Waipara series	Cretaceous
	Unconformity	

He divides the Waipara series (op. cit., p. 84) as follows:

(a) Weka Pass stone and grey marls
(b) Amuri limestone
(c) Waipara greensands
(d) Saurian beds
(e) Puke-iwi-tahi conglomerates and sandstones with coal

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The Waimangaroa series is divided into
- (a) Brunner coal horizon
- (b) Paparoa coal horizon

The Oamaru series is divided into
- (a) Ototara stone
- (b) Pareora beds
- (c) Marawhenua greensands
- (d) Waihao beds
- (e) Kaikorai coal measures

Park states (1910, 2, p. 116) that at Shag Harbor there is a well marked stratigraphical unconformity between the Oamaru formation and the Cretaceous, that at Weka Pass the unconformity cannot be distinguished, and that it cannot be recognized in the vicinity of Auckland at several places where the Waitemata beds (which are correlated with the Oamaru) overlie the hydraulic limestone (which is correlated with the Amuri limestone). He also (op. cit., p. 119) says that Hutton contended that there was an unconformity between the Amuri limestones and the Weka Pass stone, a relationship that A. McKay denied.

The three members of the Wanganui system are not divided. An unconformity at the contact of the Awatere and Oamaru in the Waipara district is mentioned (op. cit., p. 158).

Park in a recent paper (1918, 8) virtually follows Thomson, whose work is reviewed on subsequent pages.

VIEWS OF MARSHALL AND HIS ASSOCIATES

Marshall, Speight, and Cotton (1911) denied the existence of any unconformity between the Karamea and Wanganui systems of Park and contended (1911, p. 380) that

> In all exposures there is, however, a well-marked lithological series, so far as the observations of the present authors have gone, and this series will be stated in some detail when treating of the different areas. So similar is the succession in the various localities that it is possible without any great error to state a generalized rock-succession that will apply with considerable exactness to the many occurrences. This is as follows: [In descending order]
>
> 7. Loose sand with shells
> 6. Mount Brown beds; sands often calcareous
> 5. Grey marls
> 4. Greensands
> 3. Limestone
> 2. Greensand
> 1. Sands, conglomerate with coal.

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Marshall proposed for this series of rocks (1911, **1**, p. 622), the name Oamaru system and stated (1911, **1**, p. 29). "It appears however that there is no unconformity between this system [the Wanganui] and the Oamaru system."

Marshall, Speight, and Cotton (1911, pp. 399-400) also say:

A careful consideration of the stratification of these younger rocks, a brief summary of which has been given in the preceding pages, has impressed the writers with the belief that there is a single stratigraphical series of younger rocks in New Zealand, and that this series is of very general development and has a remarkably similar lithological succession in all the localities. There are, however, some problems of considerable difficulty that require solution if this statement be adopted. Briefly stated, the main problem is of this nature. At the Waipara Gorge, Amuri Bluff, and the Malvern Hills, fossils that have decidedly Cretaceous affinities are found in the lowest rocks. The most important of these are *Belemnites australis* Phillips, *Conchothyra parasitica* McCoy, *Trigonia costata* Hector, *Trigonia sulcata* Hector, *Inoceramus haasti* Hochstetter, as well as a considerable number of species of pythonomorphs and sauropterygians. In the middle beds (Mt. Brown) the Mollusca have a definitely Cainozoic appearance, and 20 per cent belong to Recent species. In the highest beds, 60 per cent (Hutton) or 71 per cent (Park) belong to Recent species. Though it is not here intended to lay great emphasis on the percentage of Recent species, these figures are quoted to show the great palaeontological difference between the lowest and the highest beds. So great is this difference that it is natural to look for breaks in the stratigraphical sequence, and the temptation is naturally great to lay emphasis on any slight local irregularity in the stratigraphy and to magnify it into an unconformity. A consideration of this difference perhaps causes one to demand from an observer who holds to the idea of a conformable sequence a special explanation of the rapid faunal change, since the whole series as developed in North Canterbury is not more than 3,000 feet thick.

* * * * *

We believe that this explanation is to be found in these three considerations: (1) A possible isolation of New Zealand during the late Mesozoic: (2) a possible lingering of archaic types: (3) the very slow rate at which the deposits accumulated.

The last two paragraphs in this paper (p. 407) are as follows:

4. Correlation has been confused because the overlapping nature of the upper members of the series has not been fully recognized. There is reason for supposing that it is correct to correlate all the conspicuous limestones of this younger series as contemporaneous.

5. So far as correlation with the European geological system is concerned, the limestone appears to be of early Oligocene age. The lowest beds of the series are perhaps Cretaceous, and the upper perhaps of Pliocene age.

This paper led to a controversy which brought forth papers by Park (1911, **3**; 1912, **5**; 1917, **6**), Morgan (1914, **1**; 1915, **2**;

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1916, 3: 1916, 4), and Marshall (1912, 3: 1916, 5: 1916, 6: 1919, 13), and additional observations by others. Morgan said (1916, 3, p. 28) regarding the proposal of Marshall, Speight, Cotton, "Though of a bold simplicity, this conception has not been fruitful in any respect save the promotion of discussion and a temporary thickening of the cloud of confusion involving an admittedly difficult problem." To this Marshall replied (1919, 13, p. 239), "It is only necessary to add that it has stimulated research in such a way that it is now definitely known that the planes that were previously thought to be breaks between different geological formations are merely stratigraphical planes in a series of continuous deposition." The discussions, additional field observations, and further collection and critical study of fossils have produced results of much value to knowledge of New Zealand geology.

In a later paper (1916, 5) Marshall undertook an account of the younger limestones of New Zealand. Three kinds of limestone are recognized, viz., polyzoal, foraminiferal, and *Globigerina* ooze. It is stated (p. 96) that "The sediment that does occur in the limestones is either extremely fine quartz sand or small fragments of volcanic rock produced by volcanic eruptions of a submarine nature. There is thus strong evidence that at the time or times at which these limestones were formed the land was reduced to comparatively small dimensions." The conclusion is reached that all the younger limestones of New Zealand are of the same geological age and mark a certain stage in the geological history of the islands. The two paragraphs next to the last in this paper (p. 99) are as follows:

> That the younger limestones of New Zealand are all of the same age, and represent approximately the same horizon, has already been suggested by Marshall, Speight, Cotton (1911). It was, however, stated in that paper that the probable age of the limestone was Oligocene, this opinion being based upon the classification of various groups of organisms that had been collected from the limestone and submitted to experts for description. The Miocene age, however, is supported not only by the molluscan fossils that have been found in the limestone itself at Otiake, but in the molluscan fauna below the limestone at Pahi and in the Trelissick basin, and in a similar fauna in the beds resting on the limestone in many localities. The percentage of Recent species in all of these cases amounts to rather more than twenty, a fact that suggests that the age is really the upper Miocene. As has been stated it is probable that too much importance has been attached to this percentage.
>
> The very general occurrence of *Amphistegina* supports the idea that the limestones are of Miocene age. This genus, however, existed in the Oligocene, though it is extremely characteristic of the Miocene. Thus

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Chapman[2] says, "The inequilateral *Amphistegina* took the place of the equilateral *Nummulites* toward the end of the Oligocene, and was the predominant form in many foraminiferal deposits of Miocene age."

For purposes of comparison it may be interesting to note here that in Central America and the West Indies *Amphistegina* is common in the uppermost Oligocene (considered basal Miocene, Aquitanian, by many paleontologists) and the Miocene; in Florida in the Miocene and Pliocene; and in the Gulf and Caribbean region it is one of the common Recent genera.

Allan Thomson (1917, **9**, p. 403) challenged the opinion that all the New Zealand limestones represent only one horizon, stating that

> In the districts within which they are typically developed the Amuri and Ototora limestones each represents the period of maximum depression or sea advance. These periods are, I contend not the same, owing to the masking of any general regional sea advance or advances that may have occurred by the provincial warpings of distinct diastrophic districts.
>
> The existence of other districts of this nature is proved, as pointed out above, by a consideration of the periods at which deposition commenced and ceased. In further support of my thesis I now propose to give paleontological evidence which supports a difference in age between the Ototara and Takaka limestones.

According to Thomson the Ototara limestone is younger than the Amuri limestone, and there seems to be no escape from this conclusion, and he says "the Takaka limestone must be regarded as younger than the Ototaran."

The age of the limestones is further discussed by Thomson in his most recent paper (1920, **15**).

The thesis that there is gradual transition from Cretaceous to Tertiary in New Zealand is further elaborated by Marshall in his paper, "Relations between Cretaceous and Tertiary rocks" (1916, **6**), and he makes comparisons with the "Relations between Cretaceous and Tertiary rocks in other countries." These comparisons do not strengthen his argument for New Zealand, because between the Eocene Tejon and the Cretaceous Chico of California there are at least two intervening geological formations with an unconformity at the top and bottom of each.[3] Marshall's mention of the Gulf of Mexico is also unfortunate when he refers to a paper on North and South Dakota.[4] The

[2] Chapman, F., Nat. Mus., Melbourne, Mem. No. 5, p. 23, 1914.

[3] See accompanying paper by Dr. Bruce L. Clark.

[4] Lloyd, E. Russell, and Hares, C. J., The Cannonball marine member of the Lance formation of North and South Dakota and its bearing on the Lance-Laramie problem: Jour. Geol., vol., 23, pp. 523-547, 1 text fig. (map), 1915.

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distance in a straight line from the southern edge of the area treated in this paper to the Gulf of Mexico is about 1250 miles, or just about the distance from Wellington to Sydney. As the Cannonball member of the Lance formation is of much interest to geologists in general, references to recent literature are given below.[5] The relations between the Cretaceous and Tertiary deposits in Chile and Patagonia are under dispute and do not serve as a good basis for any argument. However, such comparisons are interesting.

In a later paper (1919, 13, pp. 249, 250) Marshall proposes the following classification of his Oamaru system:

OAMARU SYSTEM

Probable European equivalent, Senonian to Pliocene

Series	Per cent of Recent species
Castlecliff	80 to 90
Nukumaru	70 to 80
Waipipi	60 to 70
Target Gully	30 to 40
Ototara	25 to 30
Wharekuri	20 to 25
Wangaloa	0 to 20
Waipara	Senonian

Marshall dropped his Wanganui system (1911, 1, pp. 6, 28) and placed the deposits he originally included under it in his Oamaru system, which as now defined includes all deposits beginning with Cretaceous up to the unconformity above his Castlecliff series.

VIEWS OF ALLAN THOMSON

Allan Thomson (1916, 7) proposed to form the basis of a classification by the selection of certain localities as the types of series and by the recognition of stages the names of which were derived from localities at which there are good fossiliferous exposures. The method adopted by Thomson is very similar to that of the geologists in the United States in their application of group and formation names. Thomson says:

[5] Stanton, T. W., and Vaughan, T. W., The fauna of the Cannonball marine member of the Lance formation: U. S. Geol. Survey, Prof. Paper 128, pp. 1-66, pls. 1-10, text figs. 1-3, 1920; Schuchert, Charles, Review of "The fauna of the Cannonball marine member of the Lance formation": Sci., N. S., vol. 53, pp. 45-47, 1921; Cross, Whitman, and Knowlton, F. H., Are the Lance and Fort Union formations of Mesozoic time?: Ibid., vol. 53, pp. 304-308, 1921; Mathew, W. D., The Cannonball Lance formation: Ibid., vol. 54, pp. 27-29, 1921.

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There are two objects to be aimed at in framing a classification of the younger rocks of New Zealand, and it is important to distinguish them. The first is to set up a standard of reference by which rocks from different parts of the country may be correlated with one another; the second is to correlate the various divisions of the classification thus established with their equivalents in the classifications of other parts of the world and particularly in the accepted time-scale based on the rocks of Europe.

* * * * *

It is undesirable, therefore, to speak of Eocene or Miocene rocks of New Zealand if what is meant is really rocks of the age of the Ototara limestone, the age of which has not been firmly established. * * * * * * * What we should aim at in New Zealand, then, is a similar series of stage names corresponding to all the divisions of geological time represented in our rocks.

Thomson applies the principle of priority wherever practicable in making his choice of names, and he drops from consideration the question of unconformities concerning which there was so much controversy.

The succession of beds at Oamaru, collectively called the Oamaruian series, is given as follows:

Top. Awamoa beds	Awamoan	Upper Oamaruian
Hutchinson Quarry beds and concretionary band	Hutchinsonian	
Ototara limestone	Otataran	Middle Oamaruian
Waiareka tuffs and Enfield-Windsor greensands = Ngapara greensands	Waiarekan	Lower Oamaruian
Coal-measures, sands, conglomerates, and coal seams	Ngaparan	

The Wanganuian series, named from the excellent exposures in the Wanganui district, is subdivided into the Castlecliffian and Waitotaran, with the statement that another stage may be found between the two.

The section on the west coast of the South Island is taken from Morgan, as follows:

Pliocene beds	Soft sandstone, lignite, and somewhat consolidated gravels
Greymouth series, Miocene	Blue bottom formation Cobden limestone Port Elizabeth beds Lower Kotuku conglomerate Omotumotu beds
Coal-measures (Mawheranui series.) Eocene.	Kaiata mudstone Island sandstone Brunner beds Paparoa beds

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The only stage name taken from this district is Paparoan.

Thompson summarizes his proposed classification but as it is repeated in the paper next to be reviewed, it is given on a later page.

In a later paper (1917, 9) Thomson proposes the name "Notocene" for the "younger rock series" or "covering strata" of New Zealand, in other words "all the beds lying with marked unconformity above the Hokonui or so-called Maitai series, including the Middle Cretaceous of the Clarence Valley and the Castlecliffian of Wanganui, and all the intermediate beds, but excludes the raised beaches and other surficial deposits which lie unconformably on the Castlecliffian."

For beds below the Oamaruian three stage names are proposed as follows: *Clarentian* for the Cretaceous deposits below the flint beds of northeast Marlborough in the Middle Clarence Valley; *Piripauan* (derived from the Maori name for Amuri Bluff) for the Cretaceous beds below the Teredo limestone at Amuri Bluff; and *Kaitangatan* "which includes the Kaitangata upper and lower coal-measures as described by Park (1914) and the intermediate marine horizon, but excludes the Oamaurian coal series and overlying Oamaurian marine rocks which rest unconformably, according to Park, on the Kaitangata coal-measures proper. The Kaitangatan, like the Piripauan and the Clarentian, includes both coal-beds and marine rocks, and is a group name, which may be subsequently resolved into stages, for the name of one of which 'Wangaloa' may still serve as a basis."

Thomson tabulates the components of the Notocene as follows:

GROUP NAMES	STAGE NAMES
Wanganuian	Castlecliffian Waitotaran (Other stages possible)
Oamaruian	Awamoan Hutchinsonian Ototaran Waiarekan Ngaparan (coal-beds) (Other stages possible)

(Other groups or stages possible)—Paparoan (coal-beds)
Kaitangatan
(Other groups or stages possible)
Piripauan
(Other groups or stages possible)
Clarentian.

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In this paper Thomson proposes for the "so-called Quaternary rocks" of New Zealand the name Notopleistocene, which is defined "as commencing where the Notocene * * * leaves off and continuing to the present day."

In a subsequent paper (1919, **14**) Thomson describes in detail for the area covered by his paper the Clarentian, which according to him unconformably overlies the pre-Clarentian rocks and appears to be unconformably overlain by a mudstone that conformably underlies a glauconitic sandstone which conformably lies just beneath the Amuri limestone (op. cit., fig. 5, p. 320). The sequence of rocks at Coversham is described as follows:

Sawpit Gully mudstones	3,200 feet
Nidd sandstone and mudstones	550
Cover Creek mudstones	2,000
Wharf gorge sandstones	450
Wharf mudstones	1,500
Basal conglomerates	250

The fauna of these rocks in their entirety is correlated by Woods (1917) with the Lower Utatúr of India, which is of about the same age as the Upper Gault of England, that is Albian. The Amuri limestone and the Weka Pass stone are described in detail. An apparent unconformity between the Amuri limestone and Clarentian greensandstone is described and figured (op. cit., pp. 328, 329, fig. 6) for an exposure on Herring River, but perfect conformity to the Clarentian is reported for the area from Dee Gorge to Benmore (op. cit., p. 336).

Detailed descriptions are also given of the higher Grey marls, probably of middle Oamaruian or Ototaran age, and the Great Marlborough conglomerates, questionably of upper Oamaurian age, and the Awatere beds, which include deposits ranging in age from upper Oamaruian to Waitotaran. In a postscript to this paper Thomson says that additional observations point "to the probability of an unconformity between the 'grey marls' and the lower beds."

Thomson's last paper is on the Notocene geology of the Middle Waipara and Weka Pass District (1920, **15**). It is divided, following an introduction, into three parts: 1. Descriptive geology; 2. Paleontology; 3. Correlation and classification of the Notocene, and these are followed by a bibliography. The third part of this paper might have been used in place of most of the present article, for it is an excellent summary of the present status of the correlation of the later geological formations in

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New Zealand and I shall follow it closely in the summary which will end this paper.

At the end of a brief recapitulation of Marshall's views, Thomson says (p. 407), "All this is claimed in support of his classification of all the younger rocks as a completely conformable ensemble in the Oamaru system, ranging in age from Senonian to Pliocene," and then comments as follows:

> Most of these claims are open to serious criticism. Angular unconformities are rarely seen, but are nevertheless not absent; while paleontological disconformities are also present. For instance, in the Kaiwhata River, east Wellington, there is a conglomerate containing boulders of Cretaceous sandstones, greensands, and basalts, similar to those outcropping near by, and also boulders of shell-rock, apparently derived, containing Oamaruian fossils, including *Pecten huttoni*. The conglomerate has a mudstone matrix and passes up into mudstones. There is obviously an unconformity here between two members of the younger rock-series. Morgan and Henderson have described unconformities in numerous places, and it cannot reasonably be doubted that they occur. Disconformities, or planes representing periods of standstill and non-deposition, are also known—e.g., that between the Weka Pass stone and Amuri limestone, and that between the Hutchinson Quarry beds and Ototara limestone. The probability of a paleontological disconformity between the Greta beds and the Mount Brown beds has been discussed above. Important differential earth-movements were certainly operative in the production of the great Marlborough conglomerate. There is more than one limestone in North Canterbury and in North Auckland—e. g., in the Waipara there are the Amuri limestone, the Weka Pass stone, and the Mount Brown limestones. The main limestones are of different ages in various localities, and there are at least three distinct calcareous horizons in the younger rocks—viz., those of the Amuri limestone, the Ototara limestone, and the Wairarapa limestone—with possibly a fourth in the Takaka limestone, each of these rocks representing in their respective localities the period of maximum submergence. The claims made by Marshall for his Oamaru system are not justified on the facts.

Thomson again discusses (p. 409) the relative merits of Marshall's name Oamaru system and of his own Notocene. Marshall's name certainly is not well founded according to the rules of biological nomenclature and the rules in use in the United States for geological names. It is a homonym of Hutton's Oamaru system but is not at all the same. To Marshall's criticism of Notocene as a name, Thomson retorts, "In science a term takes the meaning its author gives to it, and my definition of 'Notocene' is perfectly explicit."

The following is Thomson's general classification of the Notocene rocks in the Waipara Weka Pass district (p. 335):

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GENERAL CLASSIFICATION OF THE NOTOCENE ROCKS OF THE WAIPARA AND WEKA PASS DISTRICT

Age	Local Name	Nature of Rocks
Wanganuian	Kowhai beds	Terrestrial gravels
	Greta (or Motunau) beds	Marine gravels, silts, and blue calcareous mudstones with gravelly shell-beds.
Oamaruian	Mount Brown beds	Rubbly impure limestones and calcareous sandstones, inter-bedded with sands.
	"Grey marls"	Grey calcareous and sandy mud-stones, sandstones, and sands.
	Weka Pass stone and Weka Pass greensand	Limestone and calcareous sand-stone, passing down into a cal-careous greensand with phos-phatic nodules.
Kaitangatan	Amuri limestone	Chalky limestone, passing down into marls and glauconitic mudstones.
Piripauan	Waipara greensands	Glauconitic sands with hard, thin beds of greensandstone.
	"Saurian beds"	Purple glauconitic mudstones passing down into sands, both with yellow efflorescence.
	Ostrea bed	Sandstone cemented by poecili-tic crystals of calcite, resting on a shell-bed mainly com-posed of oyster-shells.
	Coal-measures	Carbonaceous shales, limonitic sandstones, and sands with thin seams of coal.

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Thomson in this paper (p. 323) gives the following table of the classification of the Notocene:

DIVISIONS OF THE NOTOCENE

Groups	Stages	Probable correlation
Wanganuian	Castlecliffian Waitotaran	Upper Pliocene
Oamaruian	Awamoan Hutchinsonian Ototaran Waiarekan Ngaparan Paparoan	Upper Miocene Lower Miocene Oligocene
Kaitangatan		Danian to Eocene
Piripauan		Senonian
		Turonian-Cenomanian
Clarentian		Albian

MORGAN'S CLASSIFICATION

Morgan has made important contributions to the classification of the younger geological formations. Five papers by him and one by him and Bartrum are listed in the bibliography at the end of this paper. A general correlation table by him (1918, **5**) is opposite this page.

COTTON'S CONTRIBUTIONS TO THE CLASSIFICATION OF THE NOTOCENE

The value of the researches of Speight, Cotton, and others on the stratigraphic relations of the members of the Notocene system and on the degradation of the basement rocks of those formations prior to their deposition, has been stated on preceding pages. Here it is desired to call attention particularly to Cotton's study of the Great Marlborough conglomerate (1914, **3**). This formation is composed of masses of rock ranging from 6 inches to 2 feet in diameter, small pebbles, and fine sand. Among the constituents are pieces of Amuri limestone, some blocks of which are as much as 6 inches in diameter. The

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Approximate Age	
Pliocene........	
Miocene and (?) Oligocene.	
	(
Eocene	M
	(
Late Cretaceous	W S (
Middle Cretaceous[2]	Co o S C
Early Cretaceous (Neocomian, etc.)	Po b ((

[1] The Ragl

[2] The three an example an 1169, &c. (190

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formation overlies the Grey marl in Middle Clarence Valley and Cotton could discern no unconformity between the two formations. According to Cotton the deposit is of fluviatile origin and the physiographic conditions that led to its production were due to block faulting. A part of the significance of the formation consists in the evidence it supplies in favor of earth strains and crustal deformation during the latter part of the Notocene. These strains culminated in the Kaikoura orogeny which terminated the Notocene epoch.

SUMMARY OF THE CORRELATION OF THE NOTOCENE OF NEW ZEALAND

LOWER CRETACEOUS

Morgan places as the lowest formation in the table by him, reproduced on a preceding page, the Kawhian or Awanuian and indicates its equivalence with the Neocomian of Europe, but he does not make clear the basis for his opinion. Thomson does not include these stages in his latest table (1920, **15**).

MIDDLE CRETACEOUS

The pelecypods and cephalopods of the Clarentian Cretaceous have been examined and described by Woods (1917, pp. 1-12), who reached the conclusion that the deposits are "of about the same age as the Upper Gault and Upper Greensand of England," Albian or Cenomanian, and the Lower Utatúr of India. Woods says:

> The beds of Lower Utatúr age in New Zealand rest on deposits of much earlier date, showing that the widespread "Cenomanian overlap" extended to this remote region. Here the overlap begins in the Lower Utatúr period as it does in Zululand, Pondichéry, and Japan; but in some other regions it started at a somewhat earlier period. The deposition of the beds of Lower Utatúr age in New Zealand was apparently followed by uplift, since the Middle Utatúr beds with *Acanthoceras* (Lower Chalk), which occur in Pondichéry, Madagascar, Zululand, and Japan, are not known to be represented there.

UPPER CRETACEOUS

The Piripauan of Thomson according to Woods is of upper Senonian age and is correlated by him with the Niobrara chalk. The Niobrara is not considered by American geologists as upper Senonian as suggested by Woods (1917, p. 1, **16**) but as lower Senonian. The Niobrara is far below the top of the Cretaceous in the Great Plains region of the United States, for above it are

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the Pierre shales, the Fox Hill sandstone, and whatever part of the old Laramie group that may be referable to the Cretaceous. Because of the rather definite correlation of the "Saurians beds" of Amuri Bluff and of the Waipara and Weka Pass District with the Niobrara (Austin) chalk (Woods, 1917, p. 15, 16), it is appropriate to make a few remarks about this formation. De Lapparent has definitely correlated it with the Emscherian or lower Senonian.[6] L. W. Stephenson has published an important paper on the "Cretaceous deposits of the eastern Gulf region"[7] and he now has in press a monograph of the Cretaceous Mollusca of North Carolina.[8] One of Stephenson's subzones is designated the *Mortoniceras* subzone and his studies have confirmed the correlation made by de Lapparent. The evidence in favor of this conclusion might be increased but this suffices for present purposes. If the Piripauan is really a correlative of the Niobrara (Austin) chalk, the break between it and the Clarentian may not be so great as Woods thought. It is pertinent to point out here that there was no marine connection between the Atlantic and Pacific oceans in temperate or tropical America during the disposition of the Niobrara (Austin) chalk.

The ammonite beds of the Central Kaipara district, North Island, probably are referable to the Piripauan (Marshall, 1917, **8**; Thomson, 1920, **15**, p. 385). One of the ammonite genera represented here is *Kossmaticeras*, of which Marshall describes two species.

AGE UNDETERMINED

Lying above the Piripauan are the deposits classified by Thomson as Kaitangatan. This stage includes the Wangaloa beds (Marshall, 1917, **9**) and the Amuri limestone, which also seems to be represented "in east Wellington and in north Auckland by the hydraulic limestone of Kaipara and Whangarei" (Thomson, 1920, **15**, p. 386). With regard to the gradual transition from Cretaceous to Eocene, it was one of the tenets of the faith of Hector and his supporters. Hutton first adhered to such a belief but later abandoned it, and thereafter he and Park stood together. Marshall has vigorously championed the thesis that there is passage from Upper Cretaceous to Tertiary without any stratigraphic break. If there is a break, it has not yet been

[6] De Lapparent, Traite de geologie, vol. 3, p. 1443, 1906.

[7] U. S. Geol. Survey Prof. Paper 81, 40 pp., 11 pls., 1914.

[8] North Carolina Geol. and Economic Survey, 1921.

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made clear in the literature where it is. Thomson and Speight collected a Tertiary fauna, 19 per cent Recent species, in the upper 10 feet of the Amuri limestone (Thomson, 1916, **8**, p. 51). On the Lyellian percentage basis this would be Miocene, but for reasons given by Marshall and Martin, the horizon might be Oligocene. The base of the limestone is separated from the Upper Cretaceous by between 150 and 210 feet of strata (Thomson, 1917, **9**, p. 402). If there is no break in the stratigraphic succession and if the age of its upper part be taken as Oligocene, the Amuri limestone would represent an enormous time interval —Eocene, Paleocene, and all of Upper Cretaceous down to middle Senonian. It is suggested that more study be put on the beds lying between the actual base of the Amuri limestone and the beds in which undoubtedly Upper Cretaceous (Piripauan) fossils first occur, viz., the uppermost beds of greensand that contain saurian teeth.

The nature of the beds immediately below the Amuri limestone seem to me worthy of particular note. The following section is by Thomson for Waipara River between the limestone gorge and Doctor's Gorge (1917, **9**, p. 402):

		Feet
Amuri limestone	Oamaruian Weka Pass stone	
	Hard white short-fractured limestone including a few marly bands	100
	Grey marly limestone	60
	Grey marly limestone passing gradually down into a dark blue-grey mudstone *with plant remains, glauconite at the base**	150
		Feet
	A few well-marked hard bands of greensand with saurian teeth	6
	Black glauconitic mudstone with yellow efflorescence	80
	Concretionary greensands	150
	Purple mudstones (Saurian beds) with yellow efflorescence	100
	Sulphur sands passing down into white sands	200
	Poecilitic sandstone / *Ostrea* bed	15
	Sandstones and fine conglomerates with coal	40

The presence of plant remains in the lower part of the grey marly limestone and of glauconite at its base are strongly suggestive of disconformity, if not of unconformity. Many Ameri-

*Not italicized in the original.

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can geologists are accustomed to disconformities that represent great lapses of time. In this connection attention will be directed to some statements and illustrations published by Schuchert.[10] There may be no record of important geological epochs between strata which may be structurally conformable to one another and yet of widely different ages. Another paper in point is one by Stephenson.[11] An important disconformity that long escaped notice in Florida is the one between the Alum Bluff lower Miocene and the Choctawhatchee upper Miocene.[12] This disconformity probably represents more than a third of all the Miocene strata known in the eastern and southeastern parts of the United States.

With regard to the glauconite at the base of the grey marly limestone, it is important to know whether it is autochthonous or derived. Goldman says in a recent paper:[13]

> The recognition of this association between autochthonous glauconite and stratigraphic breaks is essentially merely an extension and application of the recognition by Cayeux[14] of the connection between beds of phosphate and movement of transgression and regression. In fact, Cayeux begins his paper by calling attention to the association of glauconite and phosphate by which he seeks to explain those of the geologic past.

The Wangaloa beds are admitted by every one who has studied the fauna to possess Cretaceous affinities (Marshall, 1917, **9**, p. 459; Thomson, 1920, **15**, p. 385). I have not had an opportunity to study the fauna, except Marshall's figures, but on the basis of these figures I am willing to hazard a guess that the fauna is not far in age from the Eocene Martinez of California and the Midway of the Gulf States. As the faunas of Central America, the western part of the United States, and western South America become better known a better basis for comparison will be established. My present suggestion is that the fauna

[10] Schuchert, Charles, Paleogeography of North America, Geol. Soc. Amer. Bull., vol. 20, pp. 441-442, pls. 46, 47, 1910.

[11] Stephenson, L. W., The Cretaceous-Eocene contact in the Atlantic and Gulf Coastal Plain; U. S. Geol. Survey Prof. Paper 90, pp. 155-182, pls. 11-19, text figs. 13-20, 1915.

[12] Vaughan, T. W., Matson, G. C., and Clapp, F. G., A preliminary report on the geology of Florida: Florida Geol. Survey 2nd Ann. Rept., p. 115, 1910.

[13] Goldman, M. I., Lithologic subsurface correlation in the "Bend Series" of North Central Texas: U. S. Geol. Survey Prof. Paper 129, pp. 1-22, 1 pl., 1 text fig., 1921.

[14] Cayeux, L., Genèse des gisements de phosphates de chaux sédimentaires: Soc. Geol. France Bull. 4th ser., vol. 5, pp. 750-753, 1905.

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is not Cretaceous but that it is very low Eocene—and it should be stated that this is very nearly, if not precisely, Marshall's opinion.

The Hampden beds of Marshall (1919, **13**); Thomson, (1920 **15**, p. 390) are of nearly the age of the Wangaloa beds, the differences in the faunas perhaps being due, as Marshall suggests, to differences in the nature of the bottom.

OAMARUIAN

Many fossils have been described from this group but certain horizons are much more richly fossiliferous than others. It is supposed to range in age from Oligocene to upper Miocene. Thomson (1920, **15**, pp. 388-396) has made a special compilation of species according to beds for the Oamaru district and summarizes the data as follows:

> The percentages of Recent species in the total faunas of the province may be estimated in two ways—viz., by actual records, or by implication: i. e., if a species in the Waiarekan is also known from the Awamoan or Recent it may be credited to the intermediate rocks. The numbers of species and percentages of Recent species are as follows: By actual records—Waiarekan, 221 (Recent, 56=25 per cent); Ototaran, 90 (Recent, 28=31 per cent); Hutchinsonian, 97 (Recent, 36=37 per cent); Awamoan, 336 (Recent, 113=34 per cent): by implication—Ototaran, 178 (Recent, 69=39 per cent); Hutchinsonian, 207 (Recent, 82=40 per cent); Awamoan, 347 (Recent, 137=39 per cent). It is to be expected that when the collections from the lower stages are as exhaustive as those from the Awamoan the percentages obtained by the methods will approach one another more nearly, and also that there will be a regular increase from the Waiarekan to the Awamoan. It would be premature to assume that there had been a sudden introduction of new forms in the Awamoan, although that is the actual suggestion of the lists.

According to the Lyellian formula all of these horizons except the Waiarekan would be Pliocene. After making allowances for retarded specific changes in the Pacific, Miocene appears to be the maximum antiquity that might be assigned to the stages.

WANGANUIAN

Thomson, in the table copied in this article from his latest paper (1920, **15**, p. 323) recognized two stages in the Wanganuian group, the Waitotaran below and the Castlecliffian above, but he expressed (1920, **15**, p. 398) the opinion that the fossiliferous beds of the Palliser Bay district and Kawa Creek (see Bartrum, 1919, **3**) might occupy a position between the Awa-

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moan and the Waitotaran. Three of Marshall's series (1919, **13**, p. 249) would belong here, viz., the Waipipi with 60-70 per cent Recent species; the Nukumaru 70-80 per cent Recent species; and the Castlecliff with 80-90 per cent Recent species. The latest comprehensive lists are by Marshall and Murdock (1920, **1**). Thomson also refers to the Wanganuian the Greta beds, which have a wide distribution in the Lower Waipara, Upper Waipara, Greta, and Motunau districts. The Greta fauna of 95 species contains 67 per cent Recent species. The Wanganuian is considered to be of Pliocene by all who have studied the group.

There are in the Wanganuian two disconformities which may be of considerable importance. Marshall and Murdock say (1920, **1**, pp. 117, 118):

> Three miles to the north of Kai Iwi an old land surface can be seen distinctly in the stratification. The evidence of this is found in a stratum of beach-worn pebbles, a carbonaceous stratum with roots penetrating the blue clay beneath, and a number of molluscan bores penetrating it.
>
> * * * * *
>
> There is another instance of interbedded carbonaceous matter and of penetrating roots near the south end of the Nukumaru Beach * * *.

These two disconformities obviously divide the section into three parts, and logically the faunas should have been discussed with reference to them, but this was not done. From Marshall's measurements of strata and estimates of the rate of extinction of species, the following table has been constructed:

Upper part, Castlecliff to Kai Iwi : 1 per cent extinct for each 384 ft. of strata.

Middle part, Kai Iwi to Nukumaru : 1 per cent extinct for each 75 ft. of strata.

Lower part, Nukumaru to Waipipi : 1 per cent extinct for each 97 ft. of strata.

Castlecliff is the southernmost of the exposures and dip is southeast at an average rate of about 4°. The upper disconformity occurs between Kai Iwi and Nukumaru, the lower one at the south end of Nukumaru Beach. It is interesting to note that between Kai Iwi and Castlecliff, where no disconformity is recorded, the rate of specific change is very slow in terms of thickness of strata and that between Nukumaru and Kai Iwi, where two disconformities are recorded, the rate of specific change is more than five times more rapid than where there are

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no disconformities. Between Nukumaru and Waipipi no disconformity is recorded and the rate of specific change is slower than across the disconformities, but more rapid than between Kai Iwi and Castlecliff. The data presented by Marshall and Murdock suggest that the disconformities in the Wanganuian represent considerable time intervals, and they also suggest that the stretch between Nukumaru and Waipipi should be searched for disconformities.

CONCLUSIONS

This review makes clear the large amount of earnest work that has been done on the paleontology and stratigraphy of the late Mesozoic and the Tertiary formations of New Zealand, that the geological succession in its principal outlines has been made out, and that many important features of the stratigraphic subdivisions have been described. There is, however, much more work to be done. The fossil floras need to be studied with reference to their geological relations, and the foraminifera and bryozoa, two groups of organisms of high value in correlation, need critical study. The investigations of the Mollusca and Brachiopoda need to be carried further.

The stratigraphic interrelations of many of the formations are still inadequately known. In my review I have ventured to suggest that more attention be paid to disconformities and their possible significance.

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As Thomson has given (1913, 4, pp. 51-75) a bibliography of the paleontology of New Zealand up to and including 1912 and has included in it titles of papers that deal with the geology of the districts from which the fossils came, there is no reason to attempt here any special list of publications prior to 1913. The references here given are almost confined to papers of later date, and there has been no effort to make the list complete. My endeavor has been rather to include titles of those papers that deal with New Zealand paleontology and problems of correlations and titles of those I found helpful in understanding the status of opinion regarding the stratigraphic relations of the formations. The titles of papers that do not deal specially with New Zealand but are referred to in the text of this article are given in footnotes. I have numbered the papers under each author's name where there is more than one entry and in the text after the author's name references are made in parentheses

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3.* ——— ——, A fossiliferous bed at Kawa Creek, West Coast south of Waikato River, New Zealand: N. Z. Inst. Trans., vol. 51, pp. 101-106, 1919.

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POST-CRETACEOUS ROCKS OF AUSTRALIA

By Henry Caselli Richards

INTRODUCTION

Marine sediments of Cainozoic age in Australia are almost entirely restricted to the southern part of the Commonwealth: freshwater and fluviatile deposits are distributed over the whole Commonwealth while in eastern Australia and Tasmania there are a great wealth and variety of volcanic rocks belonging to this era.

There are many difficulties associated with the classification and correlation of these rocks, especially the marine sediments.

As will be shown later the attempts to correlate these deposits with the European developments by the Lyellian method prove very unsatisfactory, while owing to the almost total absence of Pleistocene glaciation in Australia it is very difficult to separate the Tertiary from the Post-Tertiary rocks. We have no direct evidence of the existence of a highway for the migration of marine forms between the Australian Cainozoic seas and the Tethys so that a direct comparison of the Australian Tertiary forms with those of Europe may prove fallacious.[1]

The attempts of the earlier investigators such as Sir F. McCoy, Professor Ralph Tate, W. J. Dennant and others to classify and correlate the marine sediments by the Lyellian methods resulted in considerable confusion as no two authorities were agreed as to what beds were meant in connection with the terms Eocene, Miocene, and Pliocene. In order to overcome this difficulty the late Dr. T. S. Hall and Dr. G. B. Pritchard in 1901[2] suggested a nomenclature composed of local names for the main subdivisions of the strata. They introduced the terms *Werrikooian, Kalimnan, Balcombian* and *Jan Jucian* (*Jan Jukian*, and subsequently *Barwonian*).

Differences of opinion existed not only as to the ages of the beds but also as to the sequence of the component formations and the following table showing the sequence and age was drawn up by these authors.

[1] David, T. W. E., Geology of Commonwealth: Fed. Hdbk. British Assoc. Adv. Sc., p. 285, 1914.

[2] Proc. Roy. Soc. Victoria, XIV., N. S., Pt. 2, pp. 75-81, 1902.

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	McCoy	Tate and Dennant	Hall and Pritchard
Werrikooian	——	Pleistocene (Tate) Pliocene (Dennant)	Pliocene
Kalimnan	Older Pliocene	Miocene	Miocene
Balcombian	Oligocene	Eocene	Eocene
Jan Jukian	Miocene to Oligocene	Oligocene (?) Tate Eocene	Eocene
Aldingan	——	Eocene (in part)	Eocene (in part)

The term *Werrikooian* was derived from the Parish of Werrikoo in which the Limestone Creek Beds on the Glenelg River in Western Victoria occurred. The term *Kalimnan* was given to the beds at Jimmy's Point near the mouth of the Gippsland Lakes in Victoria and near the township of Kalimna. *Balcombian* was derived from Balcombe's Bay near Mornington on Port Phillip, while *Jan Jukian* (Jan Jucian) was given to the section near Spring Creek on the coast of Bass Strait south of Geelong in the parish of Jan Juc.

One of the controversies centered around the sequence of the Jan Jukian and Balcombian. This controversy may be regarded as still existent as Mr. F. Chapman[3] postulates that the Jan Jukian is the younger series while Hall[4] in 1914 defended his earlier contention that the Jan Jukian beds are the older.

In the absence of typical fossils it is not easy to decide whether a bed is *Balcombian* or *Jan Jukian* and the wider term *Barwonian* has been given to meet this difficulty as both these horizons are well developed in the Barwon River basin in the Geelong area.[5]

In order to show the positions taken up by Chapman on the one hand and Hall and Pritchard on the other the following table[6] may be used.

[3] Chapman, F., Mem. Nat. Mus. Melbourne, No. 5, p. 9. 1914.

[4] Hall, T. S., British Assoc. Adv. Sci. Report for 1914, p. 373, 1915.

[5] Pritchard, G. B., British Assoc. Adv. Sci. Report for 1914, p. 374.

[6] Modified from table p. 298, Fed. Hdbk. British Assoc. Adv. Sci., 1914.

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Hall and Pritchard	*Chapman*
4. Werrikooian (Pliocene)	4. Upper Pliocene
3. Kalimnan (Miocene)	3. Lower Pliocene
1. { Jan Jukian (Eocene) Aldingan (Eocene in part)	2. Miocene
2. Balcombian (Eocene)	1. Oligocene

The earlier workers adopted the Lyellian method—the determination of the percentage of the recent Mollusca in the series—as the basis of classification. As pointed out by Professor David[7] and others "it is now clear that some Australian paleontologists who worked on these lines did not recognize the fact that in many of the older Tertiary deposits of Australia the marine molluscan fauna is not as was originally supposed, littoral in habit, but belongs to a moderate depth." Moreover, recent dredgings have shown that many forms in the older Australian Tertiaries which were thought to be extinct, exist today.

David,[7] Chapman,[8] Gregory,[9] and Bullen Newton[10] all advocate placing the so-called Eocene of Southern Australia in with some part of the Miocene deposits. Chapman has pointed out that the Balcombian which he (Chapman) regards as the oldest formation in Australia with marine fossils is approximately equivalent in age to the Upper Oligocene and Lower Miocene of Europe, North America, the West Indes, and Patagonia. He states that Ortman's comparison of the Patagonian beds with the Australian ones result in the latter's support of the early views of McCoy which are those of Chapman today.

Since Ortmann's pronouncement against the Lyellian method for classifying and correlating Cainozoic deposits in the southern hemisphere Hall stated[11] that he still adhered to the Lyellian method and could not accept that adopted by Ortmann which "consists in comparing each species with species of known age in the northern hemisphere, deciding which is the nearest 'ally' or 'representative' and referring the southern formations to those northern ones which yield the greatest number of 'relationships.' It passes by as of no importance all the southern forms."

[7] Op. cit. p. 285.
[8] Mem. Nat. Mus. Melbourne, No. 5, 1914.
[9] British Assoc. Adv. Sc. Report for 1914, p. 376.
[10] British Assoc. Adv. Sc. Report for 1914, p. 375.
[11] Op. cit. p. 373.

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However, the tendency today is to regard the Cainozoic deposits as mostly belonging to the middle part of the Cainozoic and reference to the paper by Mr. F. Chapman[8] "On the Succession and Homotaxial Relationships of the Australian Cainozoic System" should be made by anyone seeking evidence on that point.

Chapman's conclusions that the beds hitherto regarded as belonging to the Eocene are Oligocene and Miocene—mostly the latter—has support from Professor J. W. Gregory and Mr. R. Bullen Newton.

Gregory on the evidence of the Echinoidea, Bryozoa, and some fossil vertebrates found himself strongly supporting Chapman; the evidence of the Echinoidea being especially definite.

Bullen Newton states that Chapman's evidence in the Batesford Limestone (Barwonian) of forms such as Lepidocyclina, Amphistegina, and Lithothamnium is important as these forms characterize the Miocene beds of Europe, Java, Sumatra, Borneo, Formosa, etc. The absence of Nummulites in this limestone as shown by Chapman is also regarded by Newton as against its age being either Eocene or Oligocene.

Newton is of the opinion "that the lower Tertiary faunas of Australia presented in some cases a recent facies, in others a Miocene facies with relationships to both European and South American species of that period."[12]

Newton points out that even before Chapman had advocated a Miocene age for the Lower Marine Tertiary deposits of Australia, Dr. Ortmann in his monograph in 1902 on the Tertiary Deposits of Patagonia "has shown evidence against the presence of Eocene deposits in Australia and identified those so-called as Miocene and contemporaneous with the Pareora beds of New Zealand, Navidad series of Chili, and the Patagonian deposits.

Chapman[13] states that the most complete evidence for the succession of all the Cainozoic Series in one locality is to be gathered from the Grange Burn exposures in the Hamilton District of western Victoria and that one gets the Balcombian, Jan Jukian, and Kalimnan in that order from below upwards. This sequence he states is borne out by deep-boring at Sorrento and that the bores in the Mallee district of Victoria show the gradual transition of the Jan Jukian into the Kalimnan.

[12] R. B. Newton, op. cit. p. 375.
[13] Mem. Nat. Mus. Melbourne No. 5, pp. 46, 52, 1914.

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He holds that the homotaxial equivalents of the Balcombian in European stratigraphy are the Oligocene including the fluvio-marine beds of the south of England and the Isle of Wight, the Septaria Clay of Hermsdorf and Latdorf in North Germany, and the Tongrian of Belgium. The Magellanian beds of Patagonia and the Waimangaroa series of New Zealand he regards as belonging to this series.

The homotaxial equivalent of the Jan Jukian in Europe is, according to the same author, the Miocene (approximately Aquitanian to Tortonian) and its greatest development approximates to Burdigalian, while the homotaxial equivalent in Patagonia is the Patagonian beds of Santa Cruz and in New Zealand approximately the Oamaru Series.

BALCOMBIAN SERIES (OLIGOCENE?)

This series is restricted to the State of Victoria and the type areas are at Balcombe's Bay and Grice's Bay on the south-eastern side of Port Phillip in Victoria. At Muddy Creek near Hamilton in Western Victoria a natural section reveals beds of this age made up of blue clay containing a rich gastropod fauna and sometimes with much glauconite signifying a fairly deep water origin.

At Sorrento near the Port Phillip Heads a bore traversed at least 300 to 400 feet of this series without reaching the base of them.

The beds are made up of sands and shelly marls which are largely foraminiferal in places and containing in the shallower deposits a very rich molluscan fauna, together with the remains of fishes, crustacea, polyzoa, echinoderms, gorgonids, corals, sponges and foraminifera. Intercalated with the sandy clays and marls are brown coal deposits of a considerable thickness at Altona Bay and Newport on the northwestern side of Port Phillip, Victoria.

The chief fossils are:[14] (B. = Balcombian; J. = Jan Jukian; K. = Kalimnan). *Lamna apiculata*, *Carcharodon*, *Megalodon*, *Aturia australis* (B.—K.), *Ancilla pseudaustralis* (B.—K.), *Voluta hamiltonensis*, *Fasciolaria lamellifera*, *Eburnopsis aulacoessa*, *Cypraea ampullacea*, *C. eximia* (B. and J.), *Turbo hamiltonensis*, *Pecten murrayanus* (B.—K.), *Barbatia celleporacea* (B.—K.), *Crassatellites dennanti* (B. and J.), *Chama lamellifera*

[14] Chapman, F., Fed. Hdbk. British Assoc. Adv. Sc., pp. 298 and 300, 1914.

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(B. and J.), *Magellania corioensis* (B. and J.), *Clypeaster gippslandicus* (B.—K.), *Echinolampas gambierensis* (B. and J.), *Placotrochus deltoideus* (B.—K.), *Platytrochus vacuus, Bactronella parvula, Amphistegina lessoni* (B.—K, most abundant in J.).

JAN JUKIAN SERIES (MIOCENE?)

This is the most important of Cainozoic series, and in Victoria, South Australia and Tasmania these are marine deposits. In Victoria at Spring Creek near Torquay is the type locality and the series is there composed of glauconitic and yellow marls and polyzoal limestone. The polyzoal limestones and marls of Waurn Ponds, Moorabool River and Batesford; Curlewis; Grange Burn, Hamilton; and Flinders, all of Victoria are regarded by Chapman as belonging to this series though Hall[15] differs from Chapman with respect to some of them. In addition there are polyzoal limestone beds at Mt. Gambier and Nullabor plains in South Australia and the clays, glauconitic marls and limestones of Aldinga in the same State.

In Tasmania at Table Cape near Wynyard there are fossiferous marine beds. Fossiferous marls of this age occur also at Fyansford, Camperdown, Corio Bay and Bairnsdale in Victoria.

The older deep leads of Victoria probably represent terrestrial deposits of this age, also the leaf deposits of Bacchus Marsh and Maddingley of Victoria and Dalton and Gunning of New South Wales.

The chief fossils are: Cetacea—*Ziphius geelongensis, Parasqualodon wilkinsoni.* Fishes—*Carcharodon auriculatus, Carcharoides totuserratus.* Mollusca—*Spirulirosta curta* (only two other species known, and both from the Miocene, *viz., S. bellardii* and *S. hoernesi*), *Voluta macroptera, Volutilithes anticingulatus, Eburnopsis tesselatus, Morio wilsoni, Cypraea consobrina, C. platyrhyncha, Cerithium pritchardi, Turritella septifraga, Turbo ethridgei, Pleurotomaria tertiaria, Spondylus gaederopoides, Pecten eyrei, Limopsis insolita, Crassatellites oblonga.* Brachiopods—*Terebratula aldingae, Acanthothyris squamosa.* Crustacea—*Lepas pritchardi.* Vermes—*Ditrupa cornea* var. *wormbetiensis, Serpula ouyenensis.* Echinoids—*Cidaris australiae, Cassidulus australiae, Brissopsis archeri, Eupatagus rotundus.* Corals—*Flabellum distinctum, Deltocyathus subviola, Stephanotrochus tatei, Graphularia senescens* (J. and K.). Sponges—*Ecionema new-*

[15] Hall, T. S., p. 373, British Assoc. Adv. Sci. Report for 1914.

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beryi, Plectroninia halli, Tretocalia pezica. Foraminifera—*Gypsina howchini, Rotalia calcar, Amphistegina lessonii, Cycloclypeus pustulosus, Lepidocyclina tournoueri, L. marginata.*

KALIMNAN SERIES (LOWER PLIOCENE ?)

The shell beds of Jimmy's Point near Kalimna is the type locality. There are two other deposits in Victoria with rich faunas belonging here. They are the yellow marls of Beaumaris on Port Phillip and the upper beds at Muddy Creek near Hamilton. In the deep bore at Sorrento approximately 155 feet of rocks of this age were traversed. Other areas in Victoria are at Shelford, lower Glenelg River while in South Australia there are the Upper Aldingan beds.

The type locality at Jimmy's Point has deposits formed at a moderate depth while those of Beaumaris and Muddy Creek were those formed under shallower conditions.

The chief fossils are: Cetacea—*Scaldicetus macgeei, Physetodon baileyi.* Fishes—*Oxyrhina hastalis, Galacocerdo aduncus. Cestracion cainozoicus. Diodon formosus.* Mollusca—*Ancilla papillata, Voluta fulgetroides, V. masoni, Fusus gippslandicus, Natica cunninghamensis, Eglisia triplicata, Dentalium largicrescens, Pecten antiaustralis, Perna percrassa, Glycimeris halli. Trigonia margaritacea* var. *acuticostata, Sunetta gibberula, Mactra hamiltonensis.* Corals—*Trematotrochus clarkei, Notophyllia gracilis.*

WERRIKOOIAN SERIES (UPPER PLIOCENE ?)

The shell beds of Limestone Creek, Glenelg River, Victoria, form the deposits in the type locality. They contain a rich molluscan fauna with a large percentage of living species. The upper beds of the Moorabool viaduct, Victoria, and certain estuarine deposits of the Murray Basin belong to this series.

PLEISTOCENE

There are considerable thicknesses of coastal and inland deposits of this age.

The coastal deposits are in the nature of dune rock and occur at Freemantle in Western Australia, at Warrnambool and Sorrento in Victoria, and at Stradbroke, Moreton and Fraser Islands in Queensland.

The inland deposits are of an alluvial nature and considerable thicknesses occur in Central Australia, on the Darling

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Downs in Queensland and elsewhere. In South Australia large areas are covered with a nodular tufaceous limestone.

There are remains of several genera of now extinct marsupials in these coastal and inland deposits. Among these are remains of Diprotodon, Nototherium, Thylacoleo, Thylacinus, Sarcophilus, Procoptodon, Palorchestes, etc. In addition in Central Australia, South Australia and Queensland remains of *Genyornis* an ancestor of the emu some 13 feet high have been found.

BROWN COAL DEPOSITS[16]

In Victoria the thickest brown coal deposits known anywhere occur. There are several extensive areas such as Altona, Lal Lal, Alberton, Morwell and LaTrobe Valley.

The age of the Altona deposits is Oligocene, but the other deposits have not yet been determined in that respect, but the range is probably from Oligocene upwards. In one bore a little over 1000 feet deep, coal to an aggregate thickness of 781 feet occurred. The overburden varies from a few feet up to 500 feet in the different deposits.

VOLCANIC ROCKS[17]

In Eastern Australia and Tasmania there are a great wealth and variety of volcanic rocks. There is a natural three-fold division of these rocks there being an older and a newer series of basic to sub-basic effusions while in between is a very remarkable development of alkaline volcanic material.

The older series of basic lavas and tuffs occur in Victoria, New South Wales and Queensland. In Victoria[18] the older basalt is either contemporaneous with the Jan Jukian, or underlying, and probably post-Balcombian; or overlying the Jan Jukian, and pre-Kalimnan. In New South Wales a large development overlies leaf beds considered once to be Eocene in age but later evidence is in favor of a younger age for these beds. In Queensland there is no evidence available to fix the age of these older series except that they rest unconformably on the Jurassic beds.

The middle series of alkaline rocks extends at intervals from Casterton and Coleraine in Western Victoria through New South

[16] Herman, H., British Assoc. Adv. Sci. Report for 1914, p. 377.
[17] David and Skeats, Fed. Hdbk., British Assoc. Adv. Sci. for 1914, p. 310.
[18] Chapman, F., Mem. Nat. Mus. Melbourne, No. 5, p. 51, 1914.

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Wales up to Central Queensland, a distance of over 1200 miles. The belt along which these rocks occur is characterized by a number of dome-shaped hills, in many cases over 4000 feet high, often very abrupt and marking the site of volcanic necks. The newer series form either extensive basaltic plains or basaltic and andesitic plateaus, in some of the latter the flows have an aggregate thickness of more than 3000 feet.[19]

Interbedded with the flows in some places in New South Wales and Queensland are deposits of diatomaceous earth.

SEQUENCE OF EVENTS IN THE CAINOZOIC ERA

In Southern Australia where the marine deposits of this era are found it is believed that in Oligocene[20] times the land suffered much oscillation, the climate being warm-temperate to sub-tropical. During the Miocene there was a great movement of subsidence as shown by the limestone series with only occasional elevation when volcanic outbursts took place, the climate probably being warm-temperate.

Elevation took place again in Lower Pliocene or Kalimnan times shell-banks and shallow water marls being formed, the climate probably being similar to the present one.

In Upper Pliocene and Pleistocene times there is evidence of a cooler climate due probably to uplift. The eastern periphery of Australia was warped up to altitudes of over 3000 feet above sea level, and in New Guinea the Cretaceous to Pliocene strata were folded into mountains up to and over 15,000 feet high.[21]

A glacial age followed on this and in the Koscuisko region in New South Wales and the Western Tasmanian region evidence of heavy glaciation exists. Central Australia at this time probably enjoyed a much more rainy climate than it has at present as the remains of a fauna which would be found on plains with a good rainfall have been found in the neighborhood of Lakes Frome, Eyre and Callabonna.

During the period when glaciation took place in the Koscuisko region (the Koscuisko period) New Guinea may have been connected with Australia. Tasmania which was probably separated off from Australia in Miocene times may have been reunited again during this period.[22]

[19] Richards, H. C., Proc. Roy. Soc. Queensland, 1916.
[20] Chapman, F., Fed. Hdbk. British Assoc. Adv. Sci., p. 302, 1914.
[21] David, T. W. E., Fed. Hdbk., British Assoc. Adv. Sci., p. 287, 1914.
[22] David, T. W. E., Fed. Hdbk., British Assoc. Adv. Sci., p. 286, 1914.

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After the uplift had ceased subsidences commenced and the rift-valleys of Torres Strait, Port Curtis, Bass Strait, Port Phillip, St. Vincent and Spencer Gulfs, and of the west coast of Western Australia gradually developed.

From the Koscuisko period onward canyon cutting has taken place in the elevated coastal portions of Eastern Australia and Tasmania, the divides being constantly pushed further inland.

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THE AGE OF THE TERTIARY SEDIMENTS OF JAVA

By Dr. K. Martin, Professor in the University of Leiden and Director of the Royal Geological and Mineralogical Museum of Leiden

Translation and prefatory note by T. Wayland Vaughan
(Presented at the request of the Committee on Program)

[*Prefatory note.* Paleontologically the best known part of the East Indies is Java and for this information geologists are under great obligations to Professor Martin for the years of labor he has devoted to the subject. Recently he has summarized the results of his investigations in a paper entitled "Unsere Palaeozologische Kenntnis von Java, mit einleitenden Bemerkungen über die Geologie der Insel."[1] The importance of this volume can scarcely be overestimated. The sections of the work are as follows: Literatur; Allgemeiner Charakter der wichtigsten versteinerungsführenden Sediments; Die Lagerung der Sedimente in Verband mit Strandvershiebungen und Flussystemen; Das Alter der Sedimente; Der Erhaltungszustand der Versteinerungen; Der Habitus der javanischen Tertiär fauna und seine Bedeutung; Systematische Ubersicht der Versteinerungen; Erganzungen zur systematischen Ubersicht; Die wichstigten Fundorte der Versteinerungen.

An extensive review of each part of this publication would be appropriate in connection with this discussion of the status of the correlation of the post-Cretaceous formations in the Pacific region, but to do that would unduly prolong what is intended to be only a succinct summary. I am therefore translating the section of the paper entitled "Das Alter der Sedimente." This is done after Professor Martin informed me that it was not practicable for him to prepare a special article on the subject and referred me to his paper from which the present article is taken. This article fulfills the requirements of this discussion admirably.

I should like to call attention to Professor Martin's lucid presentation of the difficulties that beset the correlation of the Javan Tertiary formations and to his emphasis of the well-grounded opinion that species in tropical regions are more slowly transformed than in regions subjected to climatic changes. What he says regarding the relation of species to bottom conditions in the sea is also worthy of careful consideration.

An error in the table giving the stratigraphic distribution of orbitoid foraminifera needs correction. *Lepidocyclina mantelli* (Morton) Gümbel has not been found in deposits of Eocene age in America, as reference to a recent paper by Cushman[2] will show. The species is recorded by Cushman from about 30 localities in the Vicksburgian (lower) Oligocene of Mississippi, Alabama, and Florida, and appears to be characteristic of the Marianna limestone which is the middle formation of the three formations usually recognized in the Vicksburg group. Douvillé's Isolepidina, of course, has no nomenclatorial standing because the type of it, *Lepidocyclina mantelli*, is the genotype of Gümbel's Lepidocyclina.

[1] Samml. geolog. Reichs-Mus. Leiden, Beilage-Bd., pp. vii+158, 4 pls., 1919.

[2] Cushman, J. A., The American species of *Orthophragmina* and *Lepidocyclina*: U. S. Geol. Survey Prof. Paper 125-D, pp. 39-105, pls. 7-35, text-figs. 3, 1920.

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Lepidocyclina is abundant in the upper Eocene of America. Species are known from the upper Eocene as follow: Nine from the Ocala limestone of Florida and Georgia; one from the Jackson formation of Louisiana and Mississippi (this also in the Ocala limestone); one from the Island of St. Bartholomew; and two from the Island of Cuba. A few other species are doubtfully Eocene. All the species considered certainly Eocene are associated with Orthophragmina. The stratigraphic range of Lepidocyclina in America is from upper Eocene to what is considered the American equivalent of the European Aquitanian, which for reasons given elsewhere,[3] it seems to me, should be classified as Oligocene. Orthophragmina is known to occur in America in strata of both middle and upper Eocene age. Cushman has described 17 species of the genus. Specimens of a number of new American species of Orthophragmina and Lepidocyclina have been collected since the manuscript of Cushman's memoir referred to was completed.—T. Wayland Vaughan.]

The determination of the age of the Javan Tertiary deposits is beset with great difficulties, which are due in the first place to the faunas of the deposits being entirely different from the Tertiary faunas of Europe. Furthermore the Tertiary paleontology of British India was and still is very incompletely known, so that it supplies no basis for making comparisons. Because of these conditions I attempted to fix the age of the Javan faunas by means of the degree of their affinity to the living faunas of the Indo-Pacific region, particularly by estimating the percentage of Recent species in the different deposits. This method must give the relative age of the deposits with absolute certainty if the percentage estimates can be made without any limitations; this, however, is not the case; on the contrary, great obstacles stand in its way.

One of the obstacles is the difficulty of defining specific limits; another is that fossils can rarely be identified by the literature on living mollusks, the most important group for percentage estimates. It, therefore, becomes necessary to have recourse to the natural history collections for making comparisons, and all the described species are not represented in the accessible collections. Furthermore much living material has been obtained by dilettanti, and the smaller species are only poorly represented. If the number of fossils is small, it is obvious that a percentage estimate possesses only limited value.

The value of the form of a species, furthermore, is not the same in the different groups of animals, a principle illustrated by the Pliocene deposits of Sondé and vicinity. This is the case in a number of genera of molluscs not merely in a single

[3] Vaughan, T. W., U. S. Nat. Museum Bull. 103, pp. 571, 1919.

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instance; the simpler the general construction of the shell of a genus is, the more difficult becomes morphological distinction of species. A species of Conus, for example, is less certainly determined than a species of Voluta. The distribution of genera is in considerable measure dependent on local conditions; not only are some animals confined to reefs and others to muddy bottom, but there are, in my opinion, on the coasts of the great islands in the East Indies numerous other locally different kinds of environments that have not yet been adequately studied. It is probable that the transformation of species in different genera may not be accomplished with equal rapidity as has already been made clear in considering the environment. Among the different groups of animals there are species which are very restricted in the choice of their food, and these accordingly adapt themselves to changes in environment with more difficulty than others and therefore are transformed. Because of these relations the facies of a deposit can influence the percentage of Recent species.

The personal equation, which in the determination of species is not to be neglected, plays in the investigation of the Javan fossils a relatively small role because the critical species of molluscs for the percentage estimates were almost exclusively described by me. Any error due to that cause must therefore be almost equally distributed over nearly all the determinations and it, therefore, becomes negligible. The rich collections of the Leiden and British Museums serve as the basis for the comparisons with the present fauna; the species are sharply defined.

Notwithstanding this the calculated percentage is not the same as the true percentage because the Recent fauna of the region under discussion is still incompletely known, as any one can judge from the later literature. This together with the fact that not all specifically identical fossils can be surely recognized as already described species, renders necessary an increase of the calculated percentages. How this increase should be estimated there is no means of ascertaining; however, it should be considerable.

Schepman has described from a Quaternary deposit of the Celebes a great number of mollusks, whose shells are often better preserved than those seen in Recent collections. It should, therefore, be expected that all the species would be living today; but only 88 per cent can be identified with living species. In the

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Quaternary coral limestone of Timor, Boettger found 84.6 per cent of still living species of mollusks. The Quaternary of Java furnished 86 per cent, that of Grissee 90 per cent of Recent species. All of these numbers are incontestably below the true percentages, and for the less well preserved fossils from the older formations this must be true to a still higher degree.

While the percentages form the starting-point for the age determination of the Javan Tertiary deposits, the orbitoids are later often utilized as being of first importance.

Gümbel in his classic investigations on the genus Orbitoides divided the genus into five subgenera, of which four were soon placed by Meunier Chalmas (1891) in Orthophragmina, opposite which he placed Lepidocyclina, the fifth subgenus of Gümbel. Of the last genus, Gümbel knew only three species: *L. mantelli* (Morton), *L. dilatata* (Mich.), and *L. burdigalensis* Gümb. He cited as not Eocene only *L. dilata* and probably *L. burdigalensis;* the species of Orthophragmina were according to Gümbel's presentation altogether of Eocene age; and he referred *L. mantelli* to the upper Eocene. Verbeek in 1896 proposed a further separation between Orthophragmina (incorrectly called Discocyclina by him) and Lepidocyclina and was of the opinion that in Java the former occurred in the Eocene and Oligocene, the latter in all Miocene and Pliocene strata. The occurrence of Orthophragmina in the Oligocene and of Lepidocyclina in the Pliocene of Java has not been corroborated; the age of the strata concerned was not adequately known to Verbeek at that time.

H. Douvillé in 1898 reached the conclusion that Orthophragmina was known only in the Eocene, Lepidocyclina with certainty only in the Oligocene, and certainly in the Tongrian and Aquitanian, the latter of which was later considered by him and others as older Miocene. The latest investigations lead Douvillé to the conclusion regarding this matter that Orthophragmina and Lepidocyclina are not mutually exclusive and that in regard to their vertical distribution there are geographical differences. By combining the data contained in his different papers the following summary for the Tertiary deposits has been constructed:

A. Discocyclina Gümbel: Eocene B. Asterodiscus Schafhäutl: Eocene; in America lower Oligocene, with Lepidocyclina	Orthophragmina: Principal development in the Eocene; seldom in older Oligocene.

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C. Isolepidina Douv.: upper Eocene, only in America (I. mantelli) D. Eulepidina Douv.: Oligocene (upper Stampian) and principally lower Miocene (Aquitanian). E. Nephrolepidina Douv.: Oligocene (Stampian) and lower Miocene (Aquitanian and Burdigalian) F. Philolepidina Douv.: Oligocene (Stampian); only in Trinidad.	Lepidocyclina: Principal development in the older Miocene; also in the Oligocene and seldom in the later Eocene.

It is striking how nearly these results approach the opinions of Gümbel and agree with the view expressed by Sacco in 1905:

"Voilà pourquoi, bien que l'échelle stratigraphique proposée par certains auteurs, à savoir que les Orbitoides (st. s.) soient limitées au Crétacé, les *Orthophragmina* a l'Eocène, les *Lepidocyclina* à l'Oligo-Miocène, tandis que les *Miogypsina* seraient caractéristiques du Miocène, soient attrayante, je ne crois pas qu'an réalité cette distribution chronologique, acceptable pour certaines régions, soit vraie en géneral, car les *Orthophragmina*, remontent jusqu'à Oligocène, les Lepidocyclina se développent de l'Eocène au Miocène, et les *Miogypsina* paraissent déjà très abondantes dans l'Eocène et vivent peutêtre encore dans les mers actuelles."

I myself have pointed out with reference to the zoögeographical provinces of Tertiary time and in that connection emphasized that orbitoids in the Tropics can extend stratigraphically higher than in Europe. The European relations can not be simply carried over to the region of the Indian Archipelago. Furthermore the orbitoids must be considered in conjunction with the entire fauna of the strata concerned, and only as the age of the strata is definitely determined can the vertical distribution of these Foraminifera be made clear.

This is true for the Eocene, particularly for the upper Eocene Nanggulan beds, and similarly for the old Miocene Rembang beds, in which an agreement was reached between the age determination based upon the Mollusca and that based upon the Foraminifera. The Nanggulan and Rembang beds represent the most important horizons for the comparison of the Javan and European Tertiary formations.

There are at present known in Java from the Eocene only three species of Orthophragmina, of these two occur in the upper Eocene Nanggulan: in contrast fourteen species of Lepidocyclina have been described from Java. Eight of these

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species of Lepidocyclina come from the old Miocene Rembang beds (Aquitanian), and of them seven belong to Eulepidina and one to Nephrolepidina. They are accompanied by numerous individuals of *Cycloclypeus annulatus* and *C. communis,* and associated with them is *Alveolinella* (*Flosculinella*) *bontangensis*.

Those beds which contain both Lepidocyclina and mollusks uniformly contain a smaller percentage of living species than any of the other Neogene sediments. They belong together as regards time, while in the undoubtedly young Miocene or certainly Pliocene beds of Java no orbitoids have yet been observed. This bears out the assumption that a similar stratigraphic value is attributable to *Lepidocyclina* in the Indies as in Europe.

On the whole there is argument in the vertical distribution of the Javan orbitoids with the occurrence assumed for Europe by Douvillé; and for the foraminifera especially there may be recognized parallel lines of development in Europe on the one side and in the Indies and neighboring regions on the other; but in certain cases the comparison between these widely separated regions does not hold, as I have already pointed out.

This general agreement is expressed by Rütten in his summary of the vertical distribution of the foraminifera, to which he adds: "That we can on the basis of the foraminifera divide the Indian Tertiary only into large groups, and the foraminifera can not yet be utilized for refined subdivisions."

As an example, if the Nummulinae of the Nanggulan beds are considered alone, no decision can be reached as to whether the sediments should be referred to the Lutetian or to the upper Eocene, while the upper Eocene age can be deduced from the mollusks. Still more striking is the comparison between the West Progo and the Rembangs beds, the former of which posessses by far a smaller percentage of living species than the latter. In contrast to this, if a conclusion is based on the foraminifera, the West-Progo beds could not be older than uppermost Aquitanian, or even Burdigalian, while the Rembang beds according to Douvillé probably belong to the middle Aquitanian. Judging from the mollusks, the West Progo beds must be referred to the older Aquitanian.

It appears to me that in the study of the vertical distribution of the Nummulinae, the facies of the deposits is entirely too much neglected, and this is particularly true since it is established that these animals react with unusual rapidity to changes

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in environment, without reference to their general occurrence. At all events one must be cautioned that the older Miocene of the Indies on the basis of the foraminifera according to the European time scale may be divided only into Aquitanian and Burdigalian. Furthermore, even the mollusks furnish no certain criteria; for the percentage estimates until now warrant the recognition of only the principal subdivisions and stages of the Tertiary formation. For the recognition of these principal subdivisions, however, I must place a higher value on the percentage estimates than on the comparison with the occurrence of the foraminifera in Europe, on the assumption that the difficulties emphasized in the beginning of this discussion are not underestimated.

From the consideration of the percentages of living species and the mutual relationship of the faunas, the following summary of the principal known Javan deposits is constructed:

QUATERNARY

Vicinity of Grissee. 30 mollusks; 90 per cent still living. Specimens in fresh condition.

Subsurface of Batavia, up to 6 meters deep. 22 species; 86 per cent still living. State of preservation very fresh.

Trinil. Vertebrate remains, fresh-water mollusks, drifted land snails. Probably lower Pleistocene ("unteres Diluvium").

PLIOCENE

Sondé. 150 mollusks; 53 per cent still living. 11 corals; 72.7 per cent still living.

Padas Malang, east of Sonde. 19 corals; 64 per cent still living.

Pengkol, east of Padas Malang. 39 corals; 64 per cent still living.

(The Sondé, Padas Malang and Pangkol beds are of the same age.)

Pangka. 18 mollusks; 61 per cent still living.

Tji Djadjar. 34 mollusks; 56 per cent still living.

Tji Mantjeurih. 45 mollusks; 55 per cent still living. (There is some, but not very much doubt as to whether all the specimens were in place.)

Waled in Menengteng Bay. 74 mollusks; 54 per cent still living. Surface at Batavia, 74-92 meters deep. 32 species, of which 31 are mollusks; 53 per cent still living.

Gunung Gombel. 39 mollusks; 51 per cent still living.

Tjikeusik. 57 mollusks; 51 per cent still living.

YOUNG MIOCENE

West of Parungponteng. 33 mollusks; 45 per cent still living. Very nearly related to the fauna of Tjadasngampar; therefore, not to be considered Pliocene.

Tji Odeng. 37 mollusks; 43 per cent still living. Nearly related to the typical young Miocene fauna.

Palabuan-Ratu. 26 mollusks; 38 per cent still living. Relationship with the typical young Miocene fauna.

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Ngembak. Limestone with fish remains. On the surface of the following beds. [In an excavation].
Ngambak, depth 60-70 meters. 13 species, 11 of them mollusks; 38 per cent still living. Reference to the Pliocene excluded by the stratigraphic relations.
Surface at Batavia, depth 105-180 meters. 36 species, 34 of them mollusks; 36 per cent still living. Taken from the sides of excavations.
Tji Lanang. 122 mollusks; 34 per cent still living.
Liotjitjangkang. 13 species, 9 of them corals; 38 per cent still living. Reef facies of the Tjilanang beds.
Kali Tjemoro. 21 mollusks; 33 per cent still living.
Locality R of Junghuhn. 48 species, 42 of them mollusks; 31 per cent still living.
Tambakatu. 27 mollusks; 30 per cent still living.
Tjilintung-Angsana. 24 mollusks; 29 per cent still living.
Tjadasngampar, east of Parungponteng. 71 mollusks; 27 per cent still living.

OLD MIOCENE

Njalindung. 97 mollusks; 21.6 per cent still living. Including some corals, 102 species; 21.5 per cent still living. The fauna shows very considerable difference from that of Tji Lanang. Small Lepidocyclina and Miogypsina.
Tengalsari at Nanggulan. Globigerina sediments and coral limestone with Lepidocyclina (Nephrolepidina) and Miogypsina.
Rembang. 59 mollusks; 16.9 per cent still living. The rich foraminiferal fauna entirely extinct. Many Lepidocyclina (most abundant, Eulepidina; next in abundance, Nephrolepidina) and Cycloclypeus; also Alveolinella.
Batu Kutjing on Madura. } Beds rich in foraminifera which are the
Locality Q of Junghuhn. } same as those in the Rembang beds.
Localities E and S of Junghuhn. Rock with Cycloclypeus neglectus and Lepidocyclina (Eulepidina).
West-Progo Mountains. 103 mollusks; 6.8 per cent still living. Numerous Miogypsina and Lepidocyclina (most abundant, Nephrolepidina; Eulepidina rare), Cycloclypeous (isolated), and Alveolinella.
Ngembak, 104-112 m. deep. 21 species; 18 of them mollusks.
Subsurface of Grissee. 19 species, 16 of them mollusks.
(In the Ngembak and Grissee beds no species is certainly known living; Lepidocyclina is present and the fauna shows affinities to that of the Neogene.)
Reefs of Radjamandala, locality of Junghuhn. Area of the Tjilanang beds. Numerous Lepidocyclina (Eulepidina) and Heterostegina; also Cycloclypeus.

UPPER EOCENE

Nanggulan. 142 species, 136 of them mollusks; none now living. Nummulites and Orthophragmina numerous.

In the foregoing summary the beds are grouped according to the percentage of still living species simply corresponding to decrease in the number; but it scarcely need be emphasized that by this method no refined subdivision of the Tertiary deposits should be undertaken. Only the chief divisions and stages of the Tertiary formation come, as already noted, under consideration.

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while for further subdivision the preliminary criteria are lacking. Even those members above mentioned can not be recognized with full assurance for each of the localities listed without additional criteria.

For the definite determination of the horizons represented at the different localities I took the best known beds as index horizons, so that the others might be grouped with them not according to the percentage of living species alone but also according to their other faunal characteristics. The index beds are: the upper Eocene of Nanggulan, the old Miocene of Rembang and of the West-Progo Mountains, the young Miocene of Tji Lanang, the Pliocene of Sondé, and the Quaternary of Grissee.

The discrimination of all the other beds from the Eocene of Nanggulan was easily made, as that deposit possesses a fauna of entirely characteristic aspect; but it may appear strange that the deposits from the subsurface of Ngembak and Grissee are placed in the Miocene instead of considering them Oligocene. However, there is no affinity with the Eocene in their fauna, except a very uncertain Dentalium, while there are affinities with the Neogene. Since this does not correspond to what must be expected of Oligocene sediments, it would be illogical to refer them to the Paleogene and contrast them with the undoubtedly Neogene. That living species have not yet been found may be an accident, since the number of available specimens is small. Besides this there are present among the specimens, relatively many small, in part very minute forms, which are known only in the strata now being discussed and they are unusually difficult to compare with other forms.

The Njalindungs beds are also separated from the young Miocene on the basis of their faunal differences; and the calculated percentage of still living species is not much higher than in the Rembang beds. If they were considered alone, separation from the young Miocene of Tjadasngampar would scarcely be justified.

The sediments of Tjadasngampar must be considered as belonging with those west of Parungponteng; they together represent the extreme percentage (27-45) estimated for the young Miocene and belong to the same complex beds, a conclusion with which the close affinities of their organic remains harmonize. Within this complex there must be somewhat different ages, even if sharp separation into beds is not attempted.

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Although the sediments discussed above, on the one hand, can not be subdivided on the basis of their contained fossils, it is still more difficult on the other hand to discriminate between young Miocene and Pliocene. Without knowledge of the stratigraphic relations this can not be done with certainty; because *probably there is complete continuity between the Miocene and Pliocene faunas, and in places also between the sediments.* It is obviously necessary even without a sharp line of separation to assume time differences in the sediments, although the boundary can be placed only approximately and somewhat arbitrarily.

That I designate as Miocene, sediments which contain 45 per cent of living mollusks, may raise doubt, especially when this estimated percentage, for reasons already stated, is appreciably below the real percentage. In reply to this it is to be emphasized that *in similar Neogene sediments of Europe and the Indies the deposits in the latter region must contain a higher percentage of living species than the former.* This is because there was during the Tertiary time important climatic changes in the extra-tropical regions while no such changes took place in the Tropics. In the Tropics, accordingly, there were fewer factors which would modify the species and, therefore, the transformation of the fauna in the Tropics did not take place so rapidly as in our [European] region, and, consequently, more species have persisted until present time. The younger the strata are, the larger must be the difference in percentage for equivalent strata in Europe and the Indies; precise values for these can not be given.

In the foregoing discussion should be given the basis for the age determinations in the preceding summary and in the following section, which presents in detail the particular localities.

The stratigraphic relations one to another of the beds above considered obviously are only exceptionally known. The paleontological investigations can only rarely be brought into conjunction with the stratigraphic studies, a misfortune which since the study of Junghuhn's collection makes itself steadily felt and the difficulty of the work is obviously increased; because, therefore, almost every locality required special treatment and age-determination. That this is so is due to several causes.

It must next be pointed out that rarely have invertebrate fossils been hitherto systematically and intelligently collected in Java; this statement applies to the so-called geological survey

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of Java, which completely neglected even the important, richly fossiliferous Eocene sediments of Nanggulan and collections from those deposits were mostly brought together by laymen. The incompleteness of the collections are probably related to the above-noted petrographic similarity of the sediments from the different divisions and stages of the Tertiary formation. How should one who knows no fossils be able to decide what beds to select for detailed collecting? Not once can the old and the young Tertiary strata be distinguished in the field without knowledge of the fossils, and still less Miocene and Pliocene. For this reason Verbeek was not able to subdivide the Neogene of the island.

The elevation of the island since Miocene time renders more difficult the recognition of the stratigraphic relations. The sediments follow one another in the mountains of Java, as explained above, since Miocene time in a descending order, in such a way that, generally speaking, the younger deposits were always laid down at a lower level than and seaward of the older, so that consequently the areas of outcrop of the successive beds are narrow. According to my personal experience this is really the case. For instance, the interrelations of the strata of the old Miocene Njalindung beds and the typical young Miocene Tjilanangs beds can not be established, because in the region of Njalidung and Tji Lanang only one of these groups of strata is developed.

Kemmerling announces that the Tertiary of Java is characterized by "inconstant strata." But when he contends that older and younger strata can be distinguished only on a basis of their stratigraphic relations, while fossils from places which are not in stratigraphic connection suffice only for guesses as to their age, this should, taken generally, imply an extraordinary underrating of paleontology. Probably the opinion is intended to apply only to the finer subdivision of the Tertiary formation, and here stratigraphy should render a great service.

Furthermore, the first word on the determination of geological age of the sediments is spoken by paleontology, and the geologists of the Indies will never arrive at a reliable subdivision of the Tertiary strata if they do not have the support of skilled paleontologists.

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Stratigraphic and paleontologic investigations should go hand in hand in the Indies as well as in Europe.

First of all the stratigraphic relations in the strongly folded, low-lying region of northeastern Java should be studied and consideration given to the contained fossils.

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NOTES ON TERTIARY DEPOSITS IN SUMATRA, NIAS, BORNEO, CELEBES, TIMOR, AND OCEANIA

By T. Wayland Vaughan

The following notes on East Indian islands are taken from the papers listed below.[1] No attempt was made to go through the literature thoroughly. Martin gives a good summary in his third paper of the list and Yabe summarizes the information on British North Borneo.

SUMATRA

In Sumatra Tertiary strata are present as follows:

Upper Palembang beds (later Pliocene?)
Middle Palembang beds (older Pliocene?)
Lower Palembang beds (later Miocene)

Old Miocene, the orbitoidal limestone of Auer, is present, and there are local developments of Pliocene. Except Eocene, which appears to be absent, the succession of Tertiary sediments in Sumatra is similar to that in Java.

NIAS

Martin cites Douvillé as authority for the presence of Lutetian Eocene in Nias. The Miocene formations range in age from old Miocene (Aquitanian and Burdigalian) to the beginning of the Pliocene without any stratigraphic break. *Lepidocyclina sumatrensis* Brady is found at a number of places in the old Miocene. Sediments at Dahana are on the boundary between Miocene and Pliocene.

BORNEO

The Tertiary deposits of east Borneo range in age from Eocene to Pliocene. In southeastern Borneo the Eocene covers a rather large area. The Eocene sediments contain Orthophrag-

[1] Icke, H., and Martin, K., Over Tertiaire en Kwataire vormigen van het Eiland Nias: Samml. geol. Reichs-Mus. Leiden, ser. 1, vol. 8, pp. 204-252, pls. 14-18, 1907; Martin, K., Palaeozoische, mesozoische und känozoische Sedimente aus südwestlichen New-Guinea: Ibid., vol. 9, pp. 84-107, pl. 8, 1911; Miocane Gastropoden von Ost-Borneo: Ibid., vol. 9, pp. 326-336, 1 text-fig., 1914; Wann löste sich das Gebiet des indischen Archipels von der Tethys: Ibid., vol. 9, pp. 337-355, 1914; Rutten L., Studien über Foraminiferen aus Ost-Asien (Fortsetzung): Ibid., vol. 9, 9 pp., 2 pls., 1915; Yabe, H., Notes on a *Carpenteria*-limestone from B. N. Borneo: Tôhoku Imp. Univ. Sci. Repts., vol. 5, pp. 15-30, pls. 3-5, 1918.

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mina, Nummulites, Operculina, and Calcarina, an assemblage of genera identical with that found in places in the Eocene limestones of the West Indies.

The following tables are copied from Yabe. Table I is by Rutton; Table 2 is by Douvillé, based on foraminifera collected by Duxtorf.

TABLE I. VERTICAL DISTRIBUTION OF FORAMINIFERA IN JAVA

Pliocene	Clay of Sg. Boesoe near Bontang, with *Operculina complanata, Rotalia schroeteriana, Polystomella craticulata, Calcarina spengleri.*
	Marl of G. Madoepar near Bontang with *Rotalia* cf. *papillosa* and *Operculina complanata.*
Younger Miocene	Marl of Sg. Gelingseh (Sangkoelirang) with *Cycloclypeus annulatus, C. communis, Lepidocyclina glabra, L. angulosa, Operc. complanata, Amphist.* sp.; Marl of Tapian Langsat (Sg. Boengaloen) with *Miogypsina irregularis, L. ferreroi, Polyst. craticulata, Gypsina globulus, Amphist. lessoni, Oper. complanata.*
	Limestone of Sg. Gelingseh with *Cycloclypeus, Lepidocyclina, Amphistegina,* and *Operculina.*
	Marl of Sg. Mentawir (Balik Papan) with *Lepidocyclina glabra, L. angulosa, L. sumatrensis* var. *minor, Miogypsina polymorpha.*
Older Miocene	Marl and limestone of Bontang with *Miogypsina bifida, L. ferreroi, L. glabra, L. angulosa, L. sumatrensis* var. *umbilicata, L. flexuosa,* and *L. acuto;* further *Alveolinella bontangensis, Cycloclypeus communis, Gypsina globulus, Rotalia beccarii, Heterostegina depressa, Operculina complanata* and *Amphistegina* sp.; Marl and limestone of Boengaloen with *Miogyps. bifida;* Marl of Balik Papan (Sg. Blakin and Poeloe Balang) with *Miogyps. thecidaeformis, L. acuta, L. flexuosa,* and *L. ferrorei, L. sumatrensis* var. *inornata, Cycloclypeus communis, Alveolinella bontangensis, Gypsina globulus, Operculina complanata* and *Amphistegina lessonii.*
Oligocene	Marl and Limestone of Sg. Pamaloean with *L. formosa, L. inflata and L.* sp.; Limestone of the south of G. Kadango (Sg. Boengaloen) with *L. insulaenatalis, L.* cf. *munieri,? Spiroclypeus, Operculina, Amphistegina, Carpenteria* cf. *conoidea, Globigerina.*
Eocene	Limestone of G. Kadango with *Orthophragmina* and *Nummulites.*

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TABLE 2. DIVISIONS OF THE BORNEAN TERTIARY DEPOSITS

Stages		Stratigraphical divisions by Buxtorf	Fossils
Burdigalian		Sand and clay	*Lepidocyclina tournoueri, L. sumatrensis, Miogypsina, Operculina niasi.*
Aquitanian	Upper	Upper marl and limestone	*L. insulae-natalis, Spiroclypeus orbitoideus, Sp. pleurocentralis, Heterostegina margaritata, Cycloc. communis.*
	Middle	Marl with flint	*L. insulae-natalis, Cycloc. communis, Heterostegina.*
	Lower	Middle limestone	*L. formosa, Heterostegina, Alveolina.*
Stampian			*L. formosa, Nummulites subbrongniarti.*
Sannoisian		Lower sand and marl	*N. subbrongniarti, Heterostegina reticulata, Orbitolites martini, Operc. complanata.*
Bartonian			*Orthophragmina pratti, Operc.* cf. *ammonea.*
Lutetian		Lower limestone	*Orth. javana, O. omphalus, O. stellata, Hetero. reticulata, N. biarritzensis.*

On the islands Balambangan and Banguey, north of Borneo, there are, according to Rutten, sediments as follows:

Plio-Pleistocene

Miocene, s. str., with *Lepidocyclina, Cycloclypeus annulatus.*

Mio-Oligocene, with *Lepidocyclina, Spiroclypeus, Heterostegina, Operculina.*

Eocene, with *Orthophragmina.*

CELEBES

Eocene is not known to be present in Celebes, but there is in the island a large development of Tertiary deposits of younger age, Miocene and Pliocene. The older Miocene yields *Lepidocyclina* and *Miogypsina.* The Pliocene sediments in the region of Gorontalo are the equivalent of the Fialarang Pliocene of Timor.

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TIMOR

In this island besides Eocene and older Miocene, Pliocene is present over extensive areas in the interior. Fossils are abundant and well preserved in the Pliocene deposits and the age is, therefore, reliably determined.

NEW GUINEA

On the basis of foraminifera Rutten has recognized in New Guinea sediments of Eocene, Oligocene, old Miocene, late Miocene, Pliocene, and Quaternary age. The deposits were predominantly laid down in shallow water but some of the younger beds were deposited in deeper water but near the shore.

OCEANIA

I have found on the paleontology of Oceania virtually no literature on which correlations might be based although fossiliferous deposits of probably Tertiary age have been reported from several localities, the Solomon[2] and Fiji[3] islands for instance, but the fossils, mostly foraminifera, have not been critically studied. David, in a preface to Andrews's paper referred to, mentions foraminiferal "forms like *Amphistegina*, *Globigerina*, and *Textularia*" from the "bedded-limestones" of the Singatoka area, Viti Levu, Fiji, and *Charcarodon* teeth from Walu Bay, in the same island. On the Solomon Islands there are pteropod and foraminiferal limestones.[4]

There appear to be Tertiary sediments of Eocene age in New Caledonia. De Lapparent reports on the authority of Douvillé a limestone containing *Nummulites* and *Orthophragmina*,[5] which he correlates, without saying why, with the Lutetian of Europe, and he states that deposits of probably Bartonian age are also present.[6]

[2] Andrews, E. C., Notes on the limestones and general geology of the Fiji islands with special reference to the Lau Group: Harv. Coll. Mus. Comp. Bull., vol. 38, pp. 1-50, 40 pls., 4 text-figs., 1900. Marshall, op. cit., p. 20.

[3] Marshall, P., Oceania: Handb. region. Geol., vol. 2, pt. 2, p. 17, 1911.

[4] Marshall, P, op. cit., data from H. B. Guppy.

[5] DeLapparent, A., Traité géologie, 3d ed., vol. 3, p. 1531, 1906.

[6] DeLapparent, A., op. cit., p. 1544.

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BRIEF STATEMENT ON POST-CRETACEOUS FORMATIONS IN THE PHILIPPINES

By Warren D. Smith

As has been pointed out by many investigators, at this conference and elsewhere, the essential unity of the Pacific Basin is well established. We would like to point out an additional fact: namely that if the globe were flattened out, the western coastal margins of the Americas and those of eastern Asia would be seen to fall into one line, and that fairly straight, so that really western America and eastern Asia are on the same side of the Pacific.

A revised chart showing the general stratigraphy of the Philippine Islands has recently been prepared with the assistance of Dr. Roy E. Dickerson who has been making investigations in the Islands. From this chart the following table has been constructed. (See Table 1.)

As Java is the nearest region in which detailed work has been done, we take from Verbeek and Fennema[1] the following stratigraphic column, which will reveal at once the close similarity between the two regions

STRATIGRAPHY OF JAVA

(Beginning at the bottom)

1. Argillaceous schists, quartzites with quartz veins, without petrifaction (schists of the Carimuon diawa)....Age ?
2. Schists with serpentine, mica, chlorite, and argillaceous material, quartzites, some calcareous beds and interposed sills of eruptive rocks, diabase, gabbro, quartz porphyry....Cretaceous
3. Gray quartzose argillites with beds of coals, breccias of diabase, quartz, etc., conglomerates of quartz and granite, marls with alveolines and limestone with nummulites....Lower Tertiary or Eocene
4. Eruptive rocks in the preceding stage, the oldest andesites, with the characters of diorites and diabase....Lower Tertiary, Eocene
5. Terrane of Nanggoulan....Oligocene
6. Eruptive rocks at the base of the Miocene.
7. The Lower stage of the Upper Tertiary, called the "Breccia Stage," composed of breccia of eruptive Tertiary rocks with grits, shales, with some marl and beds of limestone....Lower Miocene
8. Eruptive rocks of the preceding stage....Lower Miocene
9. The middle stage for the Upper Tertiary, called the "Marly Stage," containing much marl and marly sandstones, but less of sandstone and shale; some calcareous beds. Middle Miocene with the uppermost beds in part Pliocene.
10. Eruptive rocks of the preceding stage....Middle and upper Miocene

[1] Verbeek, R. D. M., and Fennema, R., Description Geologique de Java et Madoura, Amsterdam, 1896.

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11. The most recent stage of the Upper Tertiary called the "Calcareous Stage;" much limestone and marly limestones alternating with marl..........Upper Miocene and Pliocene
12. Recent volcanic rocks; volcanoes. Miocene, Pliocene, Quaternary, and Recent.
13. Old post-Tertiary sediments with some fossil mammals........Quaternary
14. Recent post-Tertiary sediments..........Recent

With reference to formations older than the Tertiary we can only say that, aside from the radiolarian cherts which clearly are to be correlated with the Franciscan of California and hence are to be considered Jurassic in age, we know of no rocks certainly of Mesozoic or Paleozoic age in the Philippines. We are very much interested to learn that so-called "ancient" rocks are to be found in Formosa, our next-door neighbor to the north. Without fossils or undoubted stratigraphic evidence we are not willing to call schists and gneisses ancient just because similar rocks are found in the Archean. These are products of dynamic metamorphism and not of time. In several islands, notably Luzon, Masbate, and Cebu, there are red and black argillites, almost slate in places, which may be Mesozoic or older. They probably are equivalent to the "Danau Formation" (Molengraaf), or "old slates," in Borneo. No fossils have been found in these formations in the Philippines. Although in the Tertiary, perhaps in the lower Miocene conforming with the same event in America (an event which was undoubtedly world-wide), the European *"Tethys"* of Suess was closed and therefore an attempt at correlation in the latter part is unsafe. Table 2 shows a tentative correlation with the European column.

TABLE 2. THE PHILIPPINE TERTIARY (AFTER DOUVILLE)

Philippines			Borneo
c	Upper limestone with small Lepidocyclines, c.f. *verbeeki miogypsina.*	H	Burdigalien Miocene
b	Sandstone and shale with *Clycoclypeus communis, Orbitolites, alveolinella, Miogypsina.*	G F	Aquitanien Miocene
a	Middle limestone with large Lepidocyclines, *L. insulae-natalis formosa, richthofeni.*	E	
	Lower limestone with coal measures and Nummulites. *N. niasi* Verb., *Amphistegina* c.f. *niasi Lepidocyclina.*	D	Stampien Upper Oligocene

Table 2 is based on foraminifera worked up some years ago by R. Douvillé of Paris. From the recent work of Cush-

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man on living Foraminifera from Philippine waters it would seem that we cannot wholly rely on these. The long range of some of these small organisms make early conclusions based on this of doubtful value.

It has long been known that in the tropical Pacific the rate of evolution has been very slow, so slow in fact as to cause the writer to make the statement several years ago that "in the Philippines we are still in the Tertiary period." K. Martin pointed out that the percentage of living forms even in the older formations of the Tertiary is greatly in excess of what we are accustomed to find in the same formation in temperate regions; therefore, the percentages usually employed in making the divisions in the Tertiary are of no use here without modification. Recent detailed work by Dickerson on the Vigo fauna shortly to be published fully substantiates this.

The most marked recent event in the Philippine region is the great elevation that has occurred, amounting to thousands of feet. According to the testimony of fossil plants found entombed in tuff deposits at an elevation of about 1980 meters (6500 feet) above sea level, in northern Luzon, there has been a great elevation of the Philippine block within very recent times. We dare not say Recent or even Pleistocene, since the rate of evolution in the plants may have been as slow as in the case of the invertebrates. Be that as it may, the fossil leaves found at great elevations on Luzon can be determined by botanists generically, and in many cases specifically, as practically identical with those growing in the lowlands today.

In Table 3 an attempt has been made to correlate the principal formations and horizons with those of the other Malay regions and of Japan. We are well aware that this is liable to error, but it is at least suggestive and therefore may be of some benefit to future workers.

Some instances of special correlation, other than those furnished by fossils on the American side of the Pacific may be cited.

Coal. In the countries about the Pacific there is coal of several geological horizons, but in Japan, the Philippines, and Oregon most of it is Tertiary in age. The remarkable similarity, physically and chemically, between the Philippine and Oregon coal is noteworthy.

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Petroleum. In Japan, New Zealand, the Philippines, California, and Mexico, the oil is of Tertiary age. According to Australian geologists, New Zealand is called the oil arc. As in the Philippines and Japan, the oil arc is the outer arc of folded Tertiary shales and sandstones. It is true that the petroleum of California and that of the Malay region differ greatly, the former being generally of asphalt, the latter of paraffin base.

Metals. In Korea, the Philippines, Oregon, and California, and perhaps in other countries bordering the Pacific, the most productive ore deposits are associated with post-Jurassic granodiorite intrusions. These are usually contact deposits, or are in fissure veins not far from such contacts. Some less important deposits in later (Miocene) Tertiary lavas are found about the Pacific arc.

Vulcanism. Attention has long been called to the vulcanism about the Pacific, and the phrase "Circle of Fire" is the nickname given to the Pacific border by geologists. This is a happy designation not only of present conditions, but of conditions that obtained throughout the Tertiary. However, for outflows of lava comparable to those of the west coast of America in Tertiary times we must go to the great Deccan plateau of India.

In the last volume of de Margerie's admirable French translation of Suess' great work, "The Face of the Earth," is a map, compiled largely from Harker's "Natural History of Igneous Rocks," with which the writer is constrained to take issue. In this map he includes the Sierra Nevada, Cascades, and Coast Ranges of Western America in the "Andin Edifice," and the continuation of the "Asiatic Edifice" according to this map is to be found in the Rocky Mountain region of the United States. For such correlation there appear to the writer no supporting facts whatever. Both Becker and the writer have found a remarkable similarity in igneous rocks, structure, and geological history between the west coast of America and the east coast of Asia.

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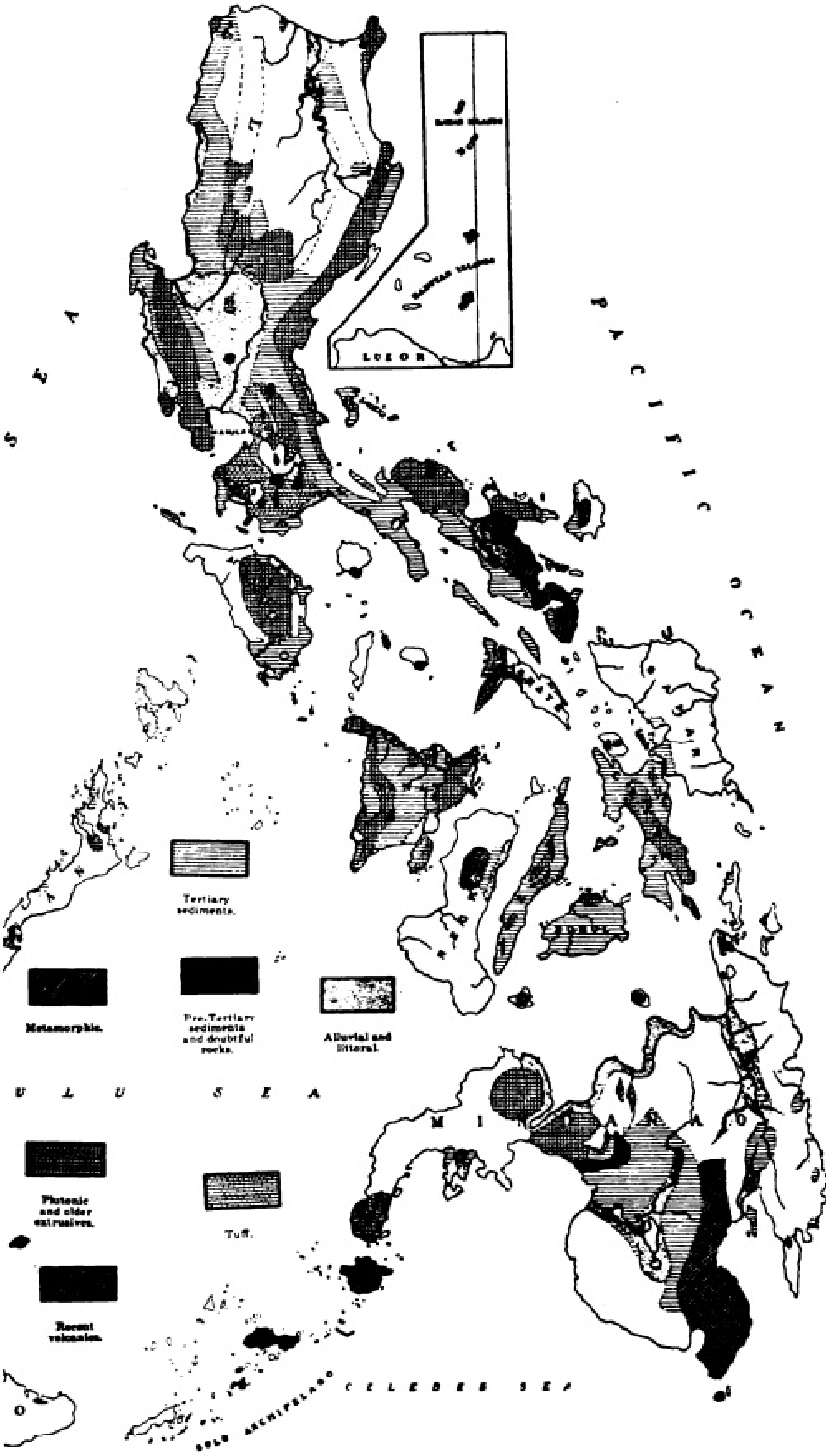


FIGURE 1. Generalized geological map of the Philippine Islands.

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RECENT STRATIGRAPHICAL AND PALEONTOLOGICAL STUDIES OF THE JAPANESE TERTIARY

By H. Yabe, Geological Institute, Tohoku Imperial University, Sendai, Japan

(Presented at the request of the Committee on Program)

The Cenozoic deposits cover an area 12,713 q. ri (1 ri = 3927.25 meters), and the younger igneous rocks, 5185 q. ri in insular Japan. Both combined cover over 65 per cent of its total area.[1] It is also certain that the Cenozoic deposits altogether attain a considerable thickness, though no one has as yet attempted a definite estimate of it.

The older division of the Cenozoic, the Tertiary, includes a considerable amount of coal, and certain deposits are petroliferous; there is also another type of the Tertiary rocks which often accompanies a particular metalliferous deposit.

In another publication,[2] I have pointed out that great diastrophic movements, which gave to the present Japanese islands their skeletal geological structure, took place during the Cenozoic. The tectonic earthquakes and the volcanic eruptions which so often disturb them in the present days have perhaps an intimate relationship with the old geotectonic scars which made their first appearance during the Tertiary.

Thus the detailed studies of the Cenozoic and especially the Tertiary formations of Japan are of great importance from both the practical and scientific sides. It must be confessed, however, that the stratigraphy and paleontology of these deposits have received little systematic study until now. It is very difficult to draw out from the orderless accumulation of records any concrete outline of the Cenozoic geology of Japan, and I think, it is premature for any such undertaking. Hence I deem it prudent to mention briefly in this paper a number of standard sections of which we have become recently more or less well informed.

[1] Outlines of the Geology of Japan: Geol. Survey of Japan, 2nd ed. 1902.

[2] Yabe, H., The Ichinokawa conglomerate and its geological meaning: Tohoku Imperial University, Sci. Repts., 2nd Ser. (Geol.) vol. 4, pp. 1-12, 1915; and Problems concerning the geotectonics of the Japanese islands: Ibid., vol. 4, pp. 75-104, 1917.

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I. CENOZOIC DEPOSITS OF NORTHERMOST SAGHALIEN; AFTER N. TICHONOVICH

The Cenozoic deposits developed in the Schmidt Peninsula of Russian Saghalien have been studied by Mr. Tichonovich, according to whom, the order of succession of the Cenozoic rocks there recognizable is as follows:

1. Miocene; the lower division: 80 sagenes.[3]
   a. Sandstone, sands and conglomerates with *Mytilus mathewsoni* Gabb. var. nov.; *turritella inezlana* Conr., *Turritella ocoyana* Conr.
   b. Coal-bearing shales underlain by variegated sandstones and marls with *Sequoia langsdorfii* Brongn.

Unconformity.

2. Miocene; the middle division: 600 sagenes.
   a. Grey sandstone with layers of clay and clayey sandstones, underlain by clayey-calcareous thin platy shale: with *Cardium decoratum* Grew., *Cardium calwattense* Glenn., *Venericardia granulata* Say, *Yoldia laevis*.
   b. Tuffaceous sandstone, white rhyolite tuff, shales, thin bedded sandstone; containing *Thyasira bisecta* Conr., *Turbo heliciformis* Dall, *Cardium decoratum* Grew.
   c. Grey quartz sand and tuffaceous sandstone, with *Pecten peckhami* Gabb.
3. Miocene; the upper division: 200 sagenes.
   Compact sandstone, tuffaceous sandstone, etc., with *Panopaea menardi* Dall.
4. Pliocene; the lower division: 100 sagenes.
   Grey clay, yellow sand, and breccia, with *Venericardia monilicosta* Gabb., *Pecten yezoensis* Say.

Interruption.

5. Pliocene; the upper division: 250 sagenes.
   Conglomerate with the pebbles of the Miocene rocks, grey, green and blue clays.

Unconformity.

6. Post Pliocene deposits.
   Conglomerate, sand and clay.

As the Neogene deposits of Hokkaido and Japanese Saghalien are not yet fully studied stratigraphically, the above subdivisions proposed by Tichonovich[4] on those of the Russian part are here introduced as a standard for comparison with the contemporaneous deposits of the other parts of Japan which are to be enumerated later on.

NOTE BY T. WAYLAND VAUGHAN

In this connection a paper by Krystofovich[5] deserves notice, and the following paragraph is copied from p. 22:

"After establishing the general contents of the Cretaceous flora in Sakhalin, we must confirm the Tertiary age of the flora of the

[3] 1 sagene = 7 feet.

[4] Tichonovich, the Schmidt Peninsula: Mem. Geol. Com., N. S., No. 82, 1914.

[5] Krystofovich, A. N., On the Cretaceous flora of Russian Sakhalin, Imp. Univ. Tokyo Coll. Sci. Jour., vol. 40, Art. 8, 73 pp., Apr. 15, 1918.

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workable seams of Mgach and also of the coal mines of Alexandrofsk. This flora of the Mgach coal mine (not of the seashore), being now quite freed of the Cretaceous elements, shows a very close similarity to the Tertiary floras of Japan, described by Nathorst (1888), also to the true Tertiary floras of the Russian Maritime Province. Consisting chiefly of Amentiflorae and containing very few ferns, this flora is quite different from that of the Cretaceous. An object of considerable interest is the occurrence of *Salvinia sp.* in Mgach. The relation between the Cretaceous and Lower Tertiary floras of Sakhalin seems to be a distant one. The proper Gyliakian flora has nothing in common with the Tertiary, probably with the only exception of *Populus arctica.* The study of the relation of the Orokkian with the Lower Tertiary in Sakhalin is yet a task for future studies, and nothing on this question can be expressed at present. The Lower Tertiary is anyhow closely allied with the flora of the Naibuchi coal-field in Japanese Sakhalin and that of Hokkaidō, as well as to the Japanese 'Pre-pliocene' floras of Nathorst."

II. TERTIARY DEPOSITS OF PART OF THE ISHIKARI COAL-FIELD, HOKKAIDO; AFTER H. IMAI AND H. YABE

There are many reports on the geology of the Hokkaido coal-fields but owing to the complicated geological structure of the area nearly all previous writers seem not to have understood the order of succession of the Tertiary rocks developed there. The conclusions given below are the results of my own studies made some 20 years ago, and recent detailed field work by Mr. Imai and myself.

Of many coal-fields in Hokkaido and Saghalien, the southern part of the Ishikari coal-field is geologically best known, and the order of succession of the Tertiary rocks developed there can be taken as a standard for the lower part of the Tertiary deposits of Hokkaido and Saghalien.

The Ishikari coal-field is situated to the east of the main course of the Ishikari-gawa, extending for 80 kilometers north to south, between the Sorachi-gawa and the Yubari-gawa, the two main tributaries of the Ishikari-gawa; the southern part of this coal-field, with the geology of which we are mostly concerned at this time, includes the well known collieries of Bibai, Pombets, Ikushumbets, Poronai, Miruto, Manji, Yubari, Oyubari, Kaede, and Noborikawa.

In this area, the Tertiary overlies the Cretaceous. The latter is divided by Yabe[6] into three groups, the Lower Am-

[6] Yabe, H., Cretaceous Cephalopoda from Hokkaido, Pt. I., 1903, and Yabe, H., Zur Stratigraphie u. Paleontologie der oberen Kreide von Kokkaido u. Sachalin, 1909.

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monites beds, the Trigonia sandstones and the Upper Ammonites beds. A part of the Trigonia sandstones, called the Hokobuchi sandstones, is covered by a thin complex of shales, platey sandstones, and coal seams in alternation; this accompanies the Nilssonia bed. Mr. S. Endo, who undertook a preliminary study of the plant remains found in this plant bed, distinguished the following species:

Pecopteris torelli Hr. ?
Nilssonia serotina Hr.
N. aff. N. orientalis Hr.
Glyptostrobus ungeri Hr. ?
Libocedrus sabiniana Hr.
Rhamnites apiculatus Lx.
Viburnum integrifolium Newb. ?
Populus penticulata Hr.

The Cretaceous deposits are unconformably overlain by a thin complex of Paleogene deposits which were called the Ishikari Series by Yabe some 20 years ago. Now Imai and Yabe propose the following subdivisions in the economically important series (in ascending order):

1. The Ishikari Series.
   a. The Horobets shale: a bed of black shale about 60 meters thick with intervening thin marl layers and containing also marl nodules; plant remains are not common and mostly indeterminable. The single well preserved specimen is determined by Endo to be *Glyptostrobus europeus* Hr.
   b. The lower coal-bearing group or Yubari group; sandstones alternating with many important coal seams; about 150 meters thick.
   c. The Wakkanappe shale; 60 meters thick, but often less. Rarely containing remains of small thin-shelled marine molluscs.
   d. The Wakkanappe sandstone; 120 meters thick. Marine, usually full of sand pipes; there are numerous beds of oysters and a few Corbicula beds intercalated in the sandstone. A part of the sandstone contains at places many mollusca, especially bivalve shells. This fossil fauna is not yet worked out; but it is at least certain that a shell bed in the Wakkanappe sandstone developed in the valley of the Pankehoroka-Yuparo, a tributary of the Yubari-gawa, contains in abundance a form of Crassitella which is hardly distinguishable from a species found in the Ashiya group of Kyushu.
   e. The middle coal-bearing group or Bibai group. Sandstone and shale in alternation, in which are intercalated many important coal seams; total thickness about 150 meters. The original specimen of *Sabal nipponica* Krystofovich is probably derived from this group.
   f. The Woodwardia zone; about 60 meters thick; characterized by a white or greyish sandstone or sandy shale, which

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is hard and compact, often flinty. Between several beds of this rock are thin platey sandstone, shale, and thin coal seams.

The Woodwardia zone contains a characteristic flora; the most prevailing types being, according to Endo:

Woodwardia cfr. maxonia Knowlton	very common
W. arcticus Hr.	rare
Osmunda sp.	
Dicksonia sp.	
Equisetum sp.	very common
Sequoia langsdorfii Brongn.	
Taxodium distichum miocenum Hr.	
Glyptostrobus ungeri Hr.	
Ficus occidentalis Lx.	common
Corylus insignis Hr.	
Zizyphus meigsii Berry ?	
Populus zaddachi Hr.	
P. arctica Hr.	
Juglans sp.	

A great unconformity.

2. The Poronai Series of a considerable thickness; black shale, in which are intercalated thin marl layers and marl nodules; glauconitic and sandy at the base. The basal sandy part is very variable in thickness from place to place. The characteristic fossils of this series are:[7]

Bulimina, several sp.	
Venericardia compressa Yok. (non Rve.)	
Nucula poronaica Yok.	
N. (Acila) picturata Yok.	
Yoldia sp.	
Leda sp.	
Thyasira bisecta Conr.?	rather rare
Tapes ezoensis Yok.	
Turritella wadana Yok.	

3. The Kawabata Series; alternating shale and sandstone; these are thin bedded in most of the series, though thick bedded near the base. Conformable with and transitional at the base to the Poronai Series (?). It contains the Poronai fauna near the base, which soon gives place upwards to another with a decidedly younger aspect. Almost contemporaneous with the marine shell bed of Morai, Atsuta-gori, province of Ishikari, which contains *Thyasira bisecta* Conrad, *Vicarya* cfr. *V. callosa* Jenkins and many others, and with the sandstone bed with *Desmostylus* cfr. *D. japanicus* Tokunaga and Iwasaki and *Trionyx desmostili* Matsumoto[8] of the Opiraushibets in the province of Teshio.

Outside the Ishikari coal-field, there are developed in Hokkaido several groups of sedimentaries of the younger Cenozoic, the most important and extensive one being that

[7] Yokoyama, Die Versteinerungen aus der Japanischen Kreide, 1890.

[8] Matsumoto, H., On a new Trionyx from Hokkaido, 1918, and Matsumoto, H., A contribution to the morphology, paleobiology and systematic of Desmostylus, 1918.

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which is now believed by Yabe to be almost contemporaneous with the Tokiwa Series of the provinces of Iwaki and Hitachi.

III. TERTIARY DEPOSITS OF THE FUKUOKA DISTRICT, PROVINCE OF MUTSU, HONSHU; AFTER S. SHIMIZU

This is one of the districts in northern Honshû (the main island of Japan) where the Tertiary deposits are well developed and their order of succession can easily be traced. The district occupies an area eight kilometers broad and 32 kilometers long along the middle course of the Mabechi-gawa, with the small town Fukuoka near its center.

Mr. S. Shimizu[9] recognized in this district the following order of succession of the Tertiary strata:

1. The Yotsuyaku Group, 224 meters thick and covering the bed-rock series (Paleozoic rocks) in clino-unconformity; it comprises in ascending order:
   a. Basal conglomerate and tuffaceous sandstone, in which are intercalated thin coal seams.
   b. Black soft shale, with some marine shells (Ostrea, etc.).
   c. Lower agglomerate.
   d. Tuffaceous sandstone, shale, and conglomerate in alternation, containing abundant impressions of leaves. Endo found the plant fossils: *Liquidambar formosana* Hance, *Fagus ferruginea* Ait. and *Oreodaphne* cfr. *Osalinensis* Berry.
   e. Middle agglomerate.
   f. Tuffaceous sandstone and shale in alternation.
2. The Nisatai Group, 10 meters thick; it consists of
   a. Conglomerate (Ostrea bed); grading in places into coarse sandstone, with shell limestone in association.
   b. Sandstone.

   Many marine shells are found in this group; of them a gigantic species of Ostrea is most attractive. This group is believed by Shimizu to rest upon the former with a slight unconformity.
3. The Yuda Group, 110 meters thick.
   a. Brownish gray sandy shale, in which are intercalated thin zones of rather incoherent sandstone.
   b. Light gray to yellowish shale with thin bands of rather incoherent sandstone, and numerous marl nodules; very fossiliferous. *Vicarya* cfr. *V. callosa* Jenkins and *Desmostylus* sp. are two noteworthy fossils from it.
   c. Tuffaceous sandstone, with intercalated thin shale layers.

   Shimizu states that the Yuda Group overlies the Nisatai and Yotsuyaku unconformably. The two fossils, named above, indicate the contemporaneity of this group with the Desmostylus bed of Hokkaido and Mino, and the Vicarya bed of Hokkaido, Hitachi, and Mino.

[9] Nakamura, the Ichinohe sheet; explanatory text to the geological map (in Japanese). At this place is given a summary of the later studies by Mr. Shimizu in the geological laboratory of the Tohoku Imperial University.

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4. The Kadonosawa Group, 280 meters thick.
   a. Tuffaceous sandy shale.
   b. Tuffaceous sandstone with intervening layers of shale; Tellina bed.
      Shimizu believes that this group is para-unconformable with the older divisions.
   A rather conspicuous unconformity.
5. The Suenomatsuyama Group, 175 meters thick.
   a. Conglomerate, grading in places into beach sand; very rich in fossils, and especially several species of Pecten are abundant.
   b. Sandstone and shale, the former sometimes cross-bedded.
6. The Takamori Group, 130 meters thick.
   a. Conglomerate;
   b. Sandstone (Echinarachinus Bed). Beside Echinarachnius, many molluscan shells and shark's teeth are found in it. Mr. Y. Ishiwara distinguished three species of shark's teeth, namely: *Oxyrhina hastalis* Ag., *Carcharodon megalodon* (Charlesworth); and *Carcharinus commersoni* Blainville.

The Suenomatsuyama and Takamori Groups are probably contemporaneous with a part of the Tokiwa Series of the Provinces of Iwaki and Hitachi, to be stated later on.

IV. CENOZOIC DEPOSITS OF THE ENVIRONS OF SENDAI, PROVINCE OF RIKUZEN; AFTER I. HAYASAKA AND H. YABE

Sendai is the site of our Geological Institute; the city is situated on the alluvial bank of the Hirose-gawa, where the stream leaves the uplifted old peneplain of Mukôyama to the coastal lowland. The 150 foot higher platform is dissected by a number of valleys which give excellent exposure of the Cenozoic rocks, of which this part of the land is constructed.[10]

1. The Sawoyama Group is the lowest division of the Tertiaries developed in the direct neighborhood of the city. A marine sandy deposit, essentially composed of sandstone of pale greenish color, with subordinate shales and sandy shales. Intercalated in it are also some tuff beds, and the shales and sandstones are partly tuffaceous. The tuffaceous rocks prevail mostly in the lower part of the group so far observed. 20 meters or more.
   The lower tuffaceous beds are fossiliferous; fossils are mostly marine shells, belonging to Nassa, Neptunea, Conus, Dentaliam, Tellina, Phacoides, etc. Also tests of diatoms and spicules are common.
2. The Mitaki Group. The Sawoyama Group apparently grades upwards to the Mitaki Group which is essentially composed of pyroclastic

[10] The stratigraphical study was first undertaken by Yabe and is now continued by Mr. Hayasaka who kindly submitted to me the present note.

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materials, tuff, tuff-breccia, agglomerate tuff, with extruded sheets of andesite; 20-25 meters or more thick. Tuff is pisolitic in part.

Over an extensive area including Matsushima and Shiogama near Sendai, there is developed a thick complex of pyroclastic rocks. Hayasaka believes that it may correspond to the Mitaki Group of Mukôyama, though the direct continuation between them is not yet observed. Overlying this complex is another, composed of sandstone and shale, with massive tuffs intercalated. This series is beautifully banded in certain horizons, and intercalated in it is a plant bed at Shiogama, from which Mr. Krystofovich[11] described lately: *Sabal sp., Juglans nigella* Hr.?, *Fagus sp., Castanea kubingi* Kov., *Ficus sp., Liquidambar formosana Hance fossilis* Nath. and *Vitiphyllum sp.* Krystofovich believes that this flora is somewhat older than the Mogi flora from the province of Hizen which is to be referred to later on.

3. The Lower Umoregi Group. This division which overlies an agglomerate tuff of the Mitaki Group consists of the following strata (in ascending order):
   - Gray sandy tuff, with plant remains, 2 meters thick; the fossils are:
     Fagus sylvatica L. var. *sieboldi Max., Sasa cfr. S. borealis* Makino and Shibata;
   - Conglomerate, 1.8 meters;
   - Grey tuff, 2 meters;
   - Cross-bedded sandstone, 7 meters;
   - Grey tuff with a lignite seam (0.7 meter), 3 meters.

4. The Tatsunokuchi Group. Mostly composed of tuffaceaus shale, but sandy in the middle; about 30 meters thick; a marine formation including four prominent shell beds. *Mactra sachalinensis* Schrenk, *Mya japonica* Say, *Panopaea generosa* and many others.

5. The middle Umoregi Group. This comprises in ascending order:
   - Sandstone, sometimes conglomeratic, 2-3 meters.
   - Clay with lignite seams; erect tree trunks are not seldom; 1 meter.
   - The Hirosegawa tuff; a massive pumiceous tuff, with no sign of stratification; 7-10 meters.
   - Pumice beds, shale, and thin lignite seams in alternation; about 2.5 meters.
   - Tuffaceous shale intercalating two thin seams of lignite; 6 meters.
   - A thin seam of lignite.

6. The Upper Umoregi Group. Total thickness 10-15 meters; a cross-bedded loose quartz sandstone, 1.5 meters at the base; the predominant rocks of the main part are shale, with occasional layers of sandstone and pumice, and also of a number of lignite seams. Loose sandstone with intercalated thin shale occupies the uppermost part. A shell bed (the Dainenji) is intercalated in it and contains Panopaea, Cardium, etc.

7. The Aobayama Group. Clay, sand and gravel; often cross-bedded; about 3-7 meters thick. This group overlies the older deposits unconformably.

8. Younger deposits on many terraces along the Hirosegawa.

[11] Krystofovich, A new fossil palm and some flora of Japan: Geol. Soc. Tokyo Jour., vol. 27, No. 322, pp. 1-20, Pls. XIII-XV, 1920.

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V. CENOZOIC DEPOSITS OF THE JÔBAN COAL-FIELD, KWANTO PLAIN AND THE BÔSÔ AND MIURA PENINSULAS; AFTER R. AOKI AND H. YABE

The Jôban coal-field covers a part of Futaba-gori and Ishiki-gori in the province of Iwaki and a part of Taga-gori in the province of Hitachi. A part of this area was stratigraphically studied in detail by Mr. S. Nakamura. His subdivisions of the Tertiaries developed in it are accepted with certain modifications by Mr. R. Aoki, who lately extended this stratigraphical study farther southwards to the provinces of Hitachi, Kazusa, Musashi, and Sagami. On the other hand, Prof. M. Yokoyama and Mr. S. Tokunaga undertook the paleontological studies of the materials derived from the upper groups of the Cenozoic deposits. The following accounts of these deposits (1–6) are essentially based on the information kindly supplied by Aoki.

1. The Shiramizu Series; about 170-45 meters; it comprises:
   a. The basal conglomerate and sandstone.
   b. The Coal-bearing Group. This is divisible into three parts, a lower and an upper coal-bearing bed, separated by the thick Shiramizu sandstone which is almost barren of coal in the lower coal-bearing beds. Nakamura found:
      Glyptostrobus ungeri Hr.
      Populus zaddachi Hr. ?
      Salix lavateri Hr.
      Betula prisca Ett.
      Quercus sp.
      Juglans acuminata Hr.
      Acer. arcticum Hr.

      In the upper beds he found:

      Glyptostrobus europeus Brongn. and *Fagus sp.*
2. The Iwaki Series; green tuffaceous sandstone, with conglomerate and coarse grained sandstone; 290-90 meters. In places it contains thin seams of coal of inferior quality. Fossils are rare though some plant remains and marine shells are known.
   a. The first sandstone.
   b. The Nametsu conglomerate.
   c. The second sandstone.
   d. The Tochikubo conglomerate.
   e. The third sandstone.
   f. The Takakura sandstone.
   g. The fourth sandstone.

   From the lower part of the Iwaki Series, Nakamura obtained; *Sequoia disticha* Hr. and *Zelkova ungeri* Ett.
   Unconformity ?
3. The Asagai Series; 290-40 meters. It comprises:
   a. The Asagai Sandstone (Cardium Bed); a greenish blue or gray, very fine grained sandstone. N. Tichonovitch found in it:

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Cardium islandicum L.
Venericardia granulata Say
Yoldia myalis Gld.
Mya arenaria L.
Tellina dissimilis Martens
T. incongrua Martens
Periploma sp.
Thyasira bisecta Conr.
Natica sp.
Turritella erosa Couth.

near the Tsuzura station, while Mr. Makiyama found abundant *Mya crassa* Grev., together with *Cardium, aff. Charrimani* Dall and *Thyasira bisecta* Conr. in the same formation exposed along the coast of Yotsukura near Taira. As a rule *Thyasira bisecta* and *Phacoides sp.*, which are two common fossils in the younger Tokiwa Series to be mentioned below, are rather poorly represented in the Asagain sandstone.

b. The Shirasaka shale; a grey or greyish black shale, very fissile and liable to break into small pieces.

Unconformity.

4. The Kamenoö Series; 870-300 meters.
   a. The Goyasu sandstone.
   b. The Mizunoya shale and sandstone.
   c. The Kamenoö shale (Leda Bed).
   d. The Misawa sandstone.

The Kamenoö shale is full of impressions of a species of Leda; besides *Phacoides sp.* is also common. The basal part of the Kamenoö shale exposed at Yotsunami contains numerous *Thyasira bisecta*. The Vicarya bed of Nakoso, with *V.* cfr. *V. callosa* Jenkins occupies a horizon somewhere in the upper part of the Kamenoö Series.

Considerable unconformity.

5. The Tokiwa Series; a very thick complex, including the Shirado tuffite of Mar. Nakamura; the prevailing rock-type is tuffaceous shale: intercalated in it are some rather thin beds of sandstone and conglomerate; agglomerates are also common. This formation contains abundant fossils, especially molluscs in places (the Thyasira-Phacoides fauna). *Carcharodon megalodon* (Charlesworth) and *Oxyrhina hastalis* Ag. are not uncommon, and *Linthis nipponica* Tokunaga is a characteristic echinoid of this formation.

Aoki distinguished the Hanareyama Series from the Tokiwa: the former is now known only from the vicinity of Kuji near the mouth of the river bearing the same name, in the province of Hitachi, and is composed of hard, coarse-grained sandstones. This group is interesting, because teeth of *Tetralophodon* cfr. *T. latidens* Clift have once been found in it. Aoki thinks this series overlies unconformably the Tokiwa and underlies unconformably the Tokyo Beds. Yabe, on the other hand, considers the Hanareyama Series as a local deposit contemporaneous with a part of the Tokiwa.

Further, Aoki proposes the name of Miura Series for a thick complex of tuffaceous shales, pumiceous sandstones, and conglomerates extensively developed in the Miura Peninsula. The shell beds of Koshiba and Kanazawa in Kuraki-gori, province of Musashi, the shell bed of Kamakura in Kamakura-gori, province of Sagami, and

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a part of the shells of Miyata in Miura-gori province of Sagami, belong to the Miura Series. Lately Prof. Yokoyama[12] published his memoir on the fossils of these shell beds and according to him, the Koshiba shell bed, which is the most prolific in fossils of all the localities enumerated above, contains 74 species of molluscs of which 30, hence 40.5 per cent are extinct. The series also not seldom contains shark's teeth, especially *Carcharodon megalodon* (Charlesworth) and *Oxyrhina hastalis* Ag. The Miura Series is also extensively developed in the Bôsô Peninsula.

Yokoyama maintains that the water in which the Koshiba shell bed was deposited was colder than that of the present coast, because the Koshiba fauna includes 17.5 per cent of the decidedly boreal species.

6. The Tokyo Beds. The Miura Series is unconformably overlaid by the next younger Tokyo Beds at Naganuma near Kamakura. The latter extends from the neighbourhood of Naganuma eastward over an extensive area of the Kwantô Plain almost to the Pacific coast, though hidden beneath the younger Narita Beds and loam for the most parts. The Kwantô Plain is a dissected platform, an uplifted plain, mostly 20-40 meters or more high, and now dissected into a group of low, flat hills which are intervened by many broad, flat valleys. The bluffs surrounding the hills often expose a series of nearly horizontal strata of which the lowest beds are tuffaceous sand and clay of bluish or grey color. These are sediments deposited on the tranquil sea bottom, not much agitated by waves, sometimes being full of sand pipes, and sometimes containing abundant remains of foraminifera. Fossil shells are very abundant in places; the bivalves having usually both valves still united, and the burrowing types being preserved in life positions.

Tokunaga[13] described 87 species of Gastropoda, three of Scaphopoda, 75 of Pelecypoda and three of Brachiopoda, in total 168 species, from shell beds of Oji, Shinagawa, and Tabata. Of these species, only 10 are considered by him as surely extinct. Further the proportion of the boreal to the tropical species is 1:1.46 in the fossil fauna of the Tokyo Beds, and 1:9.75 in the recent fauna living in the seas near Tokyo. While Tokunaga considers the Tokyo Beds of the Pleistocene age, Yokoyama believes that they are of late Pliocene age.

The topmost bed of the formation is represented at Tabata in Tokyo by an estuarine deposit of grayish clay[14]; either from this bed or from the base of the overlying sand and gravel, which belongs to the Narita Beds, Tokunaga obtained teeth of *Elephas namadicus* Falc. & Cauth. The same species was also obtained from Yokosuka. It is not certain from which of the Miura series the Tokyo beds, the Narita beds, and the fossil plants from Yokohama, determined by Nathorst and Geyler,[15] were derived. The plants described by Nathorst are:

[12] Yokoyama, M., Fossils from the Miura Peninsula and its immediate north, 1920.

[13] Tokunaga, S.: Fossils from the environs of Tokyo, 1906.

[14] Yabe, H., A new Pleistocene fauna from Tokyo: 1911.

[15] Nathorst: Zur Fossilen Flora Japans; Paleont. Abh. Berlin, vol. 4, No. 3, pp. 197-250, pls. XVII-XXX, 1888.

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cfr. Phyllites bambusoides Nath.
Fagus sylvatica L. fossilis
Quercus stuxbergi Nath.
Q. stuxbergi Nath. var. angustifolia Nath.
Q. sp.
Carpinus sp. cfr. C. yedoensis Max.
Zelkova keaki Sieb. fossilis.
Acer cfr. A. pictum Thunbg.
A. sp. cfr. A. palmatum Thunbg.
Hoveniphyllum thunbergi Nath.
Cornus submacrophylla Nath.
Leguminosites, 2 sp. (identified by Geyler.)
Styrax obassia S. Z. fossils.

Nathorst considers the flora from the bluffs of Yokohama to be younger than the Mogi flora of Hizen.

7. The Narita Beds. In Tokyo, the Tokyo Beds are overlain by a formation of sand and gravel about 10 meters thick, in which are intercalated clay beds and the whole in places grading into gravel. These sand and gravel beds are more typically developed in the extensive tract lying east of Tokyo (in the province of Shimosa), where the formation was called by Yabe, the Narita Beds. A part of this formation may perhaps be of the fluviatile origin; but in its typical development, it is certainly marine. Cross-bedding is universal in this formation. The distribution of fossils in it is very irregular, fossils being found in considerable heaps here and there. The fossiliferous part usually contains much triturated shell fragments. The shells are almost always water-worn, and the bivalves are seldom found with both valves united. Fossils are almost confined to mollusca and a species of echinoid, *Echinarachnius mirabilis* (Barn.). The great majority of mollusca belong to the Pelecypoda, which much exceeds the Gastropoda in the number of species and of individuals. The molluscan fauna of the Narita Beds does not probably differ greatly in the number of species from that of the Tokyo Beds; but a striking feature of the former is the exceeding preponderance of certain forms over the other, the most conspicuous species being

Mactra sulcataria Desh.
Tapes Philippinarum Ad. et Rve.
Tellina venulosa Schrenk
Solen krusensterni Schrenk
Diplodonta usta Gld.
Pectunculus yessoensis Sow.

8. Loam. The uppermost stratum of this extensive region is loam, a homogenous, non-stratified mass of a loose, reddish brown mixture of clayey and sandy materials, several meters thick. Intercalated in it in places is a thin layer of pumice which is in process of decomposition to a loamy material, and in places is more distinctly clayey than usual and more or less stratified at the base. This deposit covers everywhere the surface of the uplifted and dissected Kwanto plain.

9. (a) The coral bed of Noma, in the province of Awa and along the Bay of Tateyama. This deposit is younger than the loam and is worthy of special treatment. The bed is a muddy sand filling the old valley bottoms between the many terraced hills composed of

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the Miura Series (the Tokiwa Series), not far from the sea and only 15 meters higher than the present sea level. The fossils consist of large masses of reef-building corals mixed with shells. Yokoyama[18] reported from the coral bed the following species of molluscs:

Purpura alveolata Rve.
Cuma rugosa Born.
Triton obscurus Rve.
Cypraea carneola L
Trochus atropurpuratus Gld.
Fissuridea ruppellini Sow.
Cytherea tigrina Lam.
Venus lacerata Hanley.
V. af. V. jukesi Desh.
Chama of C. mul'isquamosa Gmel.
Cardita cfr. C. gubernaculum Rve.
Arca kraussi Phil.
A. fusca Brug.
Perna marsupium Lam.

These species, according to him, are now living only south of Kyushû, while the other 21 species are identical with those living in the present seas of Japan. Although Yokoyama considers this deposit to be of Pleistocene age, Yabe rather tends to the view that it may be a Post-Pleistocene deposit.

9. (b) The shell sand of Mohara and the shell bed of Cape Daitô, both in the province of Kazusa. Almost contemporaneous with the coral bed of Noma are the shell sand of Mobara and the shell bed of Cape Daitô. The shell sand of Mobara is exposed near Mobara along a stream which flows at the foot of the Tertiary hills, through the coastal plain of Kujûkurihama along the Pacific. Yokoyama found in it about 60 species of marine molluscs all still living. The shell bed of Cape Daitô also contains no extinct species of mollusca. This is exposed in a very limited area along the sea-cliffs near Cape Daitô, lying upon unconformably the Miura Series, and forms the base of an old terrace deposit.

Shell beds similar to that of Cape Diatô are also found at Inamuragasaki and Zaimokuza near Kamakura.

VI. TERTIARY DEPOSITS OF THE ECHIGO OIL-FIELDS: AFTER T. IKI

Petroleum exists in Japan exclusively in the Tertiary formation, and the western half of the province of Echigo is the most important oil district in Japan. The oil-fields in this province as a whole constitute a hilly land, the hills arranged on several lines of northeast-southwest trend. These ridges coincide usually with the anticlinal axes of the Tertiary strata, being separated by the synclinal valleys. The hills range in height between 120 and 700 meters, gradually rising from north to south.

[18] Yokoyama, M., Climatic changes in Japan since the Pliocene Epoch, 1911.

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The geological formations developed in the Echigo oil-fields are, according to Mr. T. Iki,[17] as follows:

Lower Division:
- Black shale;
- Black shale and sandstone.

Middle Division:
- Grey sandy shale.

Upper Division:
- Shale, sandstone and conglomerate;
- Clay, sand and gravel.

These are customarily considered to belong to the Tertiary, while the terrace deposits in several steps between 10 meters and 150 meters are believed to be Pleistocene in age.

1. The black shale is the lowest formation, probably over 1800 meters in thickness. In it in a number of places are intercalated thin bands of bluish fine-grained sandstone and thick characteristic beds of white or bluish tuff-sandstone which constitute the principal oil-bearing strata in this formation. In the southern part of the Echigo oil fields, conglomerate is interbedded in the shale. Fossils are rare, some brachiopods, a few molluscs and shark's teeth are known.
2. The black shale and sandstone. This is a transitional formation 600 meters thick, from the black shale to the gray sandy shale of the middle division. It is quite barren of fossils and oil.
3. The gray sandy shale. It consists of light gray sandy shale, in which in many places are intercalated subordinate layers of medium- or coarse-grained sandstone, numerous layers of agglomerate, and andesite sheets. There is also a conspicuous fossiliferous limestone bed or lens which contains abundant remains of foraminifera (especially rich in the tests of Polystomella), spines of echinoids, fragments of molluscan shells, Lithophamnium, etc. The shale is also rich in diatom remains. In total it is 300-600 meters thick. Petroliferous in the Niitsu and Nishiyama fields.
4. The shale, sandstone, and conglomerate. This series is most extensively developed along the Shinano-gawa, and is composed essentially of soft clayey shale, medium- or coarse-grained sandstone, and loose conglomerate, together with interlaminated white tuff-clay which contains numerous plant fossils and some lignite seams.

   While Nos. 1-4 are conformable, the next, No. 5, is said to be unconformable to the others.
5. The uppermost division composed of unconsolidated clay, loose sand, and gravel, occurs in limited areas; the strata are often strikingly disturbed. Fossils worthy of note have not yet been found in this series.

I know very little about the Tertiary of this region, and hence have entirely followed Mr. Iki in the above statement; beside the limestone (and other calcareous rocks) cited above,

[17] Iki, T., Preliminary note on the geology of the Echigo oil-field: Mem. Imp. Geol. Survey. 1910.

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there are in the complexes enumerated above a number of marine fossiliferous layers of importance which require future research. At present we can only say that the lower and middle divisions contain a fauna allied to the Thyasira-Phacides fauna of the Jôban coal-field, *Thyasira bisecta* itself being found in numbers at several localities in Echigo.

VII. TERTIARY DEPOSITS OF EASTERN MINO; AFTER I. SAGA

Tertiary deposits are also well developed in the eastern part of the province of Mino, over a part of two adjacent districts, Kani-gori and Toki-gori. Tsukiyoshi and Togari are two famous localities for fossils in this area.

Mr. I. Saga[18] distinguished the following four groups in the Tertiary strata:

1. The Nakamura Group.
   - a. The Nakamura Beds. Composed of sandstones and tuffaceous shales, in which are intercalated a number of lignite seams that contain numerous plant remains. Endo identified *Planera ungeri* Ett. and *Betula sachalinensis* Hr. in them.
   - b. The Hachiya Beds. A thick deposit of massive buff-breccia, with intercalated sandstone, shale and tuff zones; conspicuously darker in color than the rocks of the preceding Nakamura Beds.
2. The Hiramaki Group. While the strata of the preceding group usually shows dips of about 40, those of the next younger Hiramaki group are usually almost horizontal; the two groups, therefore, are in clino-unconformity. The predominant rocks of the latter are whitish tuffaceous shale, white and gray tuffs, and cross-bedded sandstone and conglomerate; plant fossils are numerous and remains of some land mammals are also found in it. It covers an area considerably wider than that occupied by the lower group. The mammalian remains determined by Mr. H. Matsumoto are:[19]

   Sciurid sp.
   Anchitherium hypohippoides Matsumoto
   Palaeotapirus yagii Matsumoto
   Amphitragulus minoensis Matsumoto
   Trilophodon of the T. Angustidens type
   Teleoceras pungator Matsumoto

   The preliminary study of the plant fossils by Endo gives the following result:

   Platanus ? sp.
   Cinnamomum sp.
   Ulmus braunii Hr.

[18] Saga, I., Tertiary geology of eastern Mino: graduate thesis, M. S., 1917.

[19] Matsumoto, H., Descriptions of some new fossil mammals from Kana district province of Mino, with revisions of some Asiatic fossil Rhinocerotids, 1921; Matsumoto, H., On a new archetypal cervid from the province of Mino, 1918.

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Zelkova keaki Sieb.
Castanea vulgaris Lam.
Quercus serrata Thunb.
Q. meyeri R. Ldwg. ?

3. The Tsukiyoshi Group. This and the next younger groups are lithologically quite similar; the prevailing rock type is sandy tuff of light color, with many intercalated thin layers of white compact, often silicified shale; there are numerous calcareous nodules; the strata is frequently cross-bedded.

   a. The lower division — Vicarya Beds. Fossil molluscs are abundant; characteristic are:

      Vicarya semperi Saga (Ms. nom.)
      Cerithium sp. nov.
      Potamides, 2 sp. nov.
      Munex sp. nov.
      Sanguinolaria sp. nov.
      Cyclina chinensis Chem.
      Clementia papyracea Gray

   b. The upper division. A few plant fossils are found in this part; the plant fossils collected by Rein at Tsukiyoshi and determined by Geyler are perhaps derived from this zone. These are:

      Castanea vulgaris Lam. fossilis
      Ostrea virginica Willd. fossils
      Styrax obassia S. Z. fossilis
      Quercus stuxbergyi Nath.

4. The Togari Group. Characteristic of this group are:

      Turritella sp. nov.
      Siphonalia sp. nov.
      Polynices sp. nov.
      Voluta sp.
      Cultellus sp. nov.
      Paphia sp. nov.
      Dosinia sp. nov
      Diplodonta usta Gld.
      Nucula mirabilis Hinds
      Pecten sp.

   The lower half of this group is distinguished from the upper part as the Desmostylus Beds, from which the type skull of *Desmostylus japonicus* Yoshiwara and Iwasaki[20] was taken. Many other skeletons found in it are believed to belong to other marine mammals.

5. The Daisenji Group. Composed essentially of clay, sand, and gravel, in which lignite seams are intercalated in places; it is as a whole an incoherent deposit, covering unconformably all the other older rock formations.

   Matsumoto[21] correlated the Hiramaki Group with the lower Miocene and the Togari Group with the middle; Saga determined 19 species of mollusca from the Tsukiyoshi Group and 35 from the Togari, and about 24 per cent of the former and about 29 per cent of the latter are not known from the present seas around Japan.

[20] Yoshiwara, S., and Iwasaki, J., Notes on a new fossil mammal, 1902.
[21] Matsumoto, op. cit.

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VIII. TERTIARY DEPOSITS OF NORTHERN KYUSHU; AFTER T. NAGAO AND H. YABE

An extensive Tertiary tract occupies a part of the two adjacent provinces of Chikuzen and Buzen in Northern Kyushu, the drainage area of the river Onga. It comprises the well known Chikuö coal-field. Mr. C. Kido and the late Mr. S. Matsuda[22] published 15 years ago a detailed geological account of this important colliery district, and Mr. T. Nagao is now making in our Geological Laboratory a paleontological study of a marine formation lying upon the coal-bearing groups. From this study we derived important conclusions concerning the Tertiary geology of Northern Kyshû, which differ much from the view now current among Japanese geologists.

The Tertiary deposits of the Chikuhô coal-fields are divisible into three main groups:

1. The Nogata coal-bearing formation. It covers a wide area chiefly west of the Onga-gawa, and is 180-300 meters thick; the lower part is essentially composed of sandstones and shales, the middle of sandstone, and the upper of sandstones and conglomerates. In this formation are intercalated 15-20 important coal seams, some of which are altered to natural cokes by contact with intrusive igneous sheets. Silicified wood is characteristically abundant.
2. The Otsuji coal-bearing formation. It occupies mostly the northern area, east of the Onga-gawa, and is 900-2000 meters thick; the prevailing rock is white sandstone, in which seven important coal seams are intercalated. Silicified wood is rather rare. There are characteristic conglomerate and red shale beds at the base of this formation, with which one workable coal seam is associated.
3. The Ashiya formation. This is a marine formation of a considerable extent in northern Kyushû; in the Chikuhô region, it overlies the Otsuji coal-bearing formation in apparent conformity and is distributed over the northermost part along the coast of Ashiya. It comprises three parts:
   a. Green sandstone, partly conglomeratic. 120 — 140 meters
   b. Black shale. 60 — 90 meters
   c. Light green sandstone and shale. More than 300 meters
   Some parts of this marine formation is rich in molluscs, such as Venericardia, Crassatella, Meretrix, Turritella, and many others.

The Otsuji coal-bearing formation together with the overlying Ashiya formation is well developed around the Bay of Fukuoka. The latter contains many fossils at Meinohama, a little west of the city of Fukuoka. The most conspicuous form is an Aturia, almost indistinguishable from *A. rovasendiana* Parona from the Eocene of Piedmont, Italy.

[22] Kido and Matsuda. Geological report (in Japanese) of the Chikuho coal field, 1904.

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The marine formation and the Otsuji coal-bearing formation also cover extensive areas in the coal-fields of Northen Hizen, and in the Miike coal-field, which extends over Miike-gori in the province of Chikugo and Tamana-gori in the province of Higo. Numerous fossils were obtained during the sinking of a shaft at Manda in the latter coal-field. There were determined as follows by Prof. Yokoyama:[23]

Cycas fujiiana Yok.
Cedroxylon sp.
Pentacrinus amakusensis Yok.
Terebratula miikensis Yok.
Perna nishiyamai Yok.
Pholadomya margaritacea (Sow.)
Crassatella fusca Yok.
Venericardia nipponica Yok.
Cardita mandaica Yok.
Venus mitsuiana Yok.
Fusus sp.
Aturia zigzag (Sow.)
Homolopsis japonicus Yok.
Xanthilites pentagonalis Yok.
Lamna cfr. L. cuspidata Ag.

Aturia zigzag of Yokoyama comprises two forms, one provided with narrow whorls and the other with broader ones; he compared the former with *A. zigzag* Sow. and the latter with *A. charlesworthi* Foord. The compressed form may probably be identical with the larger specimen of Aturia from Meinohama which Yabe considers to be closely allied to *A. rovasendiana.* R. F. Dickerson once communicated to Yabe that the *Pholadomya margaritacea* of Yokoyama is a form equivalent to *P. nasuta* Gabb from the lower Eocene (Martinez) of California, and the *Fusus* sp. a form equivalent to *Perissolax blakei* Gabb from the upper and lower Eocene (Tejon and Martinez) of the same state. In the Miike coal-field the Otsuji coal-bearing formation comprises at its base a thick red shale and a brackish water shell bed a little higher. A bed very similar to the latter is developed in the coal-field of Takashima, off the harbor of Nagasaki, Hizen, and also on an adjacent island Kôyagi where it is found in association with a red shale bed.

In the Miike coal-field, the Otsuji formation attains about 150 meters, and the Ashiya formation 550 meters or more. There is no sign of a stratigraphical break between these two formations. The Manda fauna, according to Yokoyama, indicates either the Paleocene or Eocene of Europe.

[23] Yokoyama, Some Tertiary fossils from the Miike coal-field, 1911.

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Yokoyama found also *Crassatella fusca* in a collection of fossils from the island of Amakusa; hence, the same formation seems to be developed on the island. In the western half of the Amakusa-Shimojima, a coal-bearing formation extends from north to south. The coal-bearing formation consists of shale, sandstone and conglomerate; sandstone and conglomerate predominating in the lower part, shale, and sandstone with coal seams in the middle, and shale in the upper. In the lower part, there are several fossiliferous zones; it is very likely that a few ammonites of the Senonian age reported by Yabe are derived from these zones. At present, however, we have no knowledge of the stratigraphical details of these Senonian rocks, the coal-bearing formation and the younger marine sandstone which is equivalent to the Ashiya formation; many of the Japanese geologists are convinced of the Cretaceous age of the Amakusa coal.

Fossil plants are found in the coal-bearing formations of Kyshû; those derived from the Takashima coal mines and lately described by Krystofovich[24] are *Sabal sp. aff. S. nipponica* Krysht; and *Acrostichium hesperium* Newberry. R. Florin[25] also describes another *Salvinia formosa* Hr. Further the occurrence of a Nelumbium is recorded by Nathorst and Kryshtofovich. The latter author correlated the plant bed of Takashima with the Green River Group of North America. It is also to be noticed at this place that a species of Crassatella found commonly in the Ashiya formation is discovered in the Wakkanappe sandstone of the Ishikari coal-field.

On the island of Kyushû there are two other Tertiary formations quite distinct from the preceding ones. One of them, which is older, is extensively developed along the Pacific coast of the province of Hiuga; at the base is a thick arkosic sandstone, seldom containing foraminifera. Upon it lie a number of shale beds which sometimes accompany a thin coal seam of inferior quality; the shales of the upper horizon are considerably calcareous and noduliferous. These are overlain by a tuffaceous greenish gray sandstone containing *Operculina complanta* Defr. abundantly in places. This Operculina sandstone extends for a

[24] Krystofovich, Occurrence of the palm, *Sabal nipponica*, n. sp. in the Teritiary Rocks of Hokkaido and Kyushu: Jour. Geol. Soc. Tokyo, vol. 35, pp. 59-66, Pl. xli, 1918.

[25] Florin, Eine Uebersicht der fossilen Salvinia-Arten mit besonderer Berücksichtigung eines Fundes von *Salvinia formosa* Hr. im Tertiär Japans, 1919.

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distance of about 60 kilometers along the coast. Though without convincing paleontological evidence, this complex is considered to be considerably younger than the Ashiya formation, probably being of Miocene age.[26]

A still younger formation (younger Pliocene) is developed in the province of Hizen; it consists mainly of white and gray tuffs and shales. Mogi near Nagasaki is famous for the plant bed belonging to this formation. This plant bed was first noticed by Nordenskjold and his collection has been studied by Nathorst. Lately Florin revised the determinations of this same material and utilized another collection. A contemporaneous deposit is known from the island of Amakusa. Nathorst and Florin[27] determined 80 species of plant leaves from the Mogi bed, the greater part of which belongs to the plants now living in this part of Japan, though there are certain remarkable species in the fossil flora such as *Taxodium distichum* Rich. and *Fagus ferruginea* Ait. This fossil flora indicates that a colder climate than that of the present prevailed in that district in the younger Pliocene.

THE TERTIARY DEPOSITS OF THE SOUTHERN ISLANDS WITH THE ZONES OF CHARACTERISTIC FORAMINIFERA; AFTER H. YABE

In the southern islands of Japan, the Riukiu Islands, the Ogasawara (Bonin) Islands, and Taiwan (Formosa), there are also developed extensive deposits of the Cenozoic. The Tertiary deposits, especially older ones, contain many intercalated calcareous beds or are composed of calcareous rocks with numerous foraminifera, some of which are very useful as zone-indicators. The occurrences of these rocks have lately been treated by Yabe[28] in a paper written in Japanese. The following is an abstract of this paper.

1. Eocene.
   a. Nummulitic tuff of Haha-jima in the Ogasawara Group; it is full of nummulites which Tokunaga assigned to *N. javanus* Verbeek and *N. bagueleusis* Verbeek. A part of the microspheric form resembles *N. vredenburgi* and another

[26] Yabe, H., Notes on Operculina rocks from Japan with remarks on "Nummulites" cumingi Carpenter, 1918.

[27] Nathorst, Contributions á ia flore fossile du Japon: Kungl. Sv. Vet. Akad (2) vol. 20, No. 2, pp. 1-92, 1883, and Florin, Zur Kenntnis der Jungtertiären Pflanzenwelt Japan, Ibid., vol. 61, No. 1, pp. 1-71, 1920.

[28] Yabe, H., Tertiary rocks with higher Foraminifera from Japan. 1920.

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part *N. laevigatus;* hence, the tuff is believed to represent the upper Lutetian. The other fossils found in associated with the foraminifera are:

Sagenina regularis Douvillé
S. expansa Yabe
Placopsilina cenomana Orb.
Lituotuba sp.
Orthophragmina colcanapi R. Douvillé?
Alveolina sp. pl.
Schizaster nummuliticum Tok.
Nerita cfr. N. schmedeliana Chemn.
Lithothamnium sp. pl.

b. Pellatispira limestone of Hahajima, and Ishigaki-jima in the Riukiu Group. The limestone from Haha-jima contains:

Pellatispira madraszi v. Hantken
P. madraszi v. Hantken var. douvilléi Boussac
P. orbitoideus Provale?
Orthophragmina cfr. O. fritschi Douvillé
Nummulites, a small species.
Archaeolithothamnium sp.
Lithothamnium sp.
Lithophyllum ?

The limestone from Ishigaki-jima is, on the other hand, almost solely composed of the tests of *Pellatispira madraszi* and var. *douvilléi*, and of Lithothamnium.

c. Orthophragmina limestone in Kagi-chô, Taiwan. The limestone was collected by Mr. Deguchi in the so-called "Clay-slate Formation." It consists of at least 2 species of Orthophragmina and a small species of Nummulites belonging to Radiatae.

The limestones of b. and c. are believed to represent the upper Eocene.

2. Upper Oligocene or lowest Miocene. Spiroclypeus limestone of Kôtosho (Botel-tobago), near Taiwan, and Chichi-jima, the Ogasawara Group. The limestone from the first locality contains:

Spiroclypeus pleurocentralis Carter (in abundance) Lepidocyclina sumatrensis Brady (rare)

That from the second locality:

Spiroclypeus sp.
Alveolina sp.
Orbitolites sp.

Tokunaga has stated that he found some large specimens of Lepidocyclina in the second mentioned limestone. These perhaps belong to Eulepidina. These two limestones, I believe, represent either the upper Oligocene or the lowest Miocene.

3. Lower Miocene (Burdigalian stage). Foraminiferal rocks of this stage are extensively distributed in Taiwan, in the Riukiu Islands, and also in a certain limited area on the main island of Japan (Honshû). In Taiwan, a foraminiferal limestone is intercalated in the coal-bearing formation of Taihoku-chô; a similar complex is developed on the island of Iriomote-jima in the Riukiu Islands.

The limestone contains:

Lepidocyclina angularis Newton and Holland
L. sumatrensis Brady
L. verbeeki Newton and Holland
Amphistegina lessoni Orb.

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Cycloclypeus communis Martin
Myogypsina sp.
Cellepora formosensis Newton and Holland
Lithothamnium ramosissimum Reuss

Tokunaga found in the complex:

Pecten placunoides Martin
Astriclypeus integer Tok.
Echinodiscus formosus Tok.

Limestones nearly contemporaneous with this are also known from many other parts of Taiwan.

On the main island of Japan, the distribution of the foraminiferal rocks of the Burdigalian stage is confined to the several localities in the provinces of Sagami, Kai, Kôzuke and Musashi; in the former two provinces, small lenticular masses of limestone are intercalated in the uppermost part of the so-called Misaka Series, which is a thick complex of pyroclastic materials, and characterized by the fossils:

Lepidocyclina verbeeki Newton and Holland
Miogypsina sp.
Gypsina inhoerens Schultze
Amphistegina lessoni Orb.
Rotalia schroeteriana Parker and Jones
Lithothamnium, sp. pl.

At Kamikosaka in the province of Kôzuke more than 50 thin layers of impure limestone or rather calcareous sandstone are intercalated in a thick complex of shale about 650 meters thick. The fossils contained in the calcareous rock are:

Lepidocyclina japonica Yabe (Ms. nom.)
L. angulosa Provale
L. glabra Rutten
Miogypsina sp.
Amphistegina lessoni Orb.

A peculiarity of this rock is the total absence of calcareous algae which are so often found in association with foraminifera: on the other hand, numerous fragmental tests of various Bryozoa are present.

A recent discovery shows that there exists in the Chichibu basin (in the province of Musashi) in the upper part of the Tertiary a sandstone belt which is in part highly calcareous, being full of nodular Lithothamnium; it also contains Miogypsina and Lepidocycline though rarely. These occurrences of Lepidocyclina (Nephrolepidina) and Miogypsina rocks in the provinces of Kôzuke and Musashi are important, for there are different kinds of evidence indicating the contemporaneity of these rocks with a Tertiary formation that is developed in neighboring areas and contains: *Thyasira bisecta* Conr., *Phacoides sp.* and *Mya crassa* Grev.

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NOTE ON THE TERTIARY GEOLOGY OF ALASKA

By ALFRED H. BROOKS, U. S. Geological Survey

(Presented at the request of the Committee on Program)

The plant-bearing beds of the Kenai formation are the only extensive Tertiary deposits of Alaska.[1] Arthur Hollick, who has studied this fossil flora, assigns it to the Eocene and correlates it with the so-called "Arctic Miocene" of the Europeans. Some marine Miocene and Pliocene sediments occur along the Pacific margin of Alaska. Pliocene beds are more widespread in the north Arctic coastal plain region.

The Kenai formation probably will be eventually subdivided and should then be termed a group. Rocks of this horizon occur at many localities along the entire Pacific seaboard and probably in the Aleutian Islands. The Kenai is also widely distributed over the interior of Alaska, especially in the Cook Inlet and Susitna-Matanuska region. It is typically made up of friable or hard conglomerates, soft or hard sandstone, and shales. The formation nearly everywhere carries fossil plants and coal. Most of the coal is lignitic but where the formation has been profoundly folded, the carbonaceous beds are altered to bituminous and in some places to anthracite coal.

The Kenai so far as known is of fluviatile origin, and the individual beds are non-persistent along the strike. In most localities the Kenai rocks are less than a thousand feet thick, but as they are nearly everywhere the surface formation this is a minimum rather than an actual thickness. In the Matanuska coal field[2] the Kenai is represented by the Chickaloon formation. Where the top and bottom of the formation is exposed the plant-bearing beds are about 4000 feet thick, and at Kachemak Bay, on Cook Inlet, they measure some 2000 feet,[3] which is a minimum. A belt of folded conglomerates, sandstones, and shales, with some interbedded volcanics, occurs on the north flank of the Alaska Range, stretching for about 50 miles eastward from Mt. McKinley. These rocks, which are about 2000 feet thick, have

[1] Brooks, Alfred H., The geography and geology of Alaska: U. S. Geol. Survey Prof. Paper 45, pp. 237-241, 1906.

[2] Martin, G. C., and Katz, F. J., Geology and coal fields of the lower Matanuska Valley: U. S. Geol. Survey Bull. 500, pp. 15, 42-45, 1912.

[3] Martin, G. C., and others. Geology and mineral resources of the Kenai Peninsula: U. S. Geol. Survey Bull. 587, pp. 67-89, 1915.

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been called the Cantwell formation formerly provisionally assigned to the Carboniferous,[4] but now known to contain Kenai plants.[5] A few miles north of the Cantwell formation lies the Nenana coal-field where there are extensive lignite deposits associated with friable conglomerates and shale, the whole series measuring 1200 to 1500 feet in thickness.[6] Some fragmentary plant remains in these coal measures have been provisionally assigned to the Kenai, but the structural evidence points to the conclusion of their having been deposited since the Cantwell formation (Kenai) was folded.

The Kenai rocks are believed to have been the deposits of an extensive Eocene river system which traversed much of Alaska. These rivers, like the present ones, had their sources far inland and in part beyond the Canadian border. They also, like the present rivers, emptied into the Pacific Ocean, Bering Sea, and probably into the Arctic. Along the Pacific the Eocene shore line was probably farther out to sea than the present coast line. The Eocene shore line of Bering Sea was probably not greatly different from that of the present.

Miocene beds have been found at several places along the Pacific seaboard.[7] The Miocene history of Alaska is little known, but it appears that there was a slight transgression of the sea after the close of the Eocene, when marine deposits were laid down in local embayments. This transgression does not seem to have gone north of Bristol Bay, an indentation of the southeastern part of Bering Sea.

In Pliocene times the transgression continued locally along the Pacific seaboard and during this period a part of the North

[4] Brooks, Alfred H., The Mt. McKinley Region: U. S. Geol. Survey Prof. Paper 70, pp. 49, 52-55, 72-83, 1911.

[5] Capps, S. R., The Kantishna District: U. S. Geol. Survey Bull. 687, pp. 37-44, 1920.

[6] Capps, S. R., The Bonnifield Region: U. S. Geol. Survey Bull. 501, pp. 26-28 and 54-62, 1912.

Martin, G. C., The Nenana coal-field: U. S. Geol. Survey Bull. 664, pp. 6 and 7, 1919.

[7] Martin, G. C., Geology and mineral resources of the Controller Bay Region: U. S. Geol. Survey Bull. 335, pp. 39-41 and 63, 1908.

Maddren, A. G., Mineral deposits of the Yakataga Region: U. S. Geol. Survey Bull. 592, pp. 126-132, 1914.

Atwood, W. W., Geology and mineral resources of parts of the Alaska Peninsula: U. S. Geol. Survey Bull. 467, pp. 66-69 and 71, 1911.

Martin, G. C., Preliminary report on the petroleum in Alaska: U. S. Geol. Survey Bull. 719, pp. 35-36, 1921.

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Arctic coastal plain was also submerged.[8] In the Nome district of the Seward Peninsula marine fossils have been found in the ancient sea beaches which have yielded much placer gold.[9] Dr. William H. Dall[10] has determined the age of these marine invertebrates as Pliocene, but the geologists who have mapped this area hold that these ancient beach deposits can not be older than Pleistocene.

Correlations of the Alaska Tertiary with that of other provinces are not yet very definite. The Kenai as stated is the equivalent of the Arctic Miocene of Europeans, and is no doubt, broadly speaking, the equivalent of the plant-bearing continental deposits of the Laramide epoch. The Kenai problem is now being studied by Dr. Arthur Hollick. It is probable that the plant-bearing beds of Kamchatka and other parts of Eastern Siberia are to be correlated with the Kenai. Few fossils have been found in the Alaska Miocene and Pliocene, and these furnish no definite tie points with the Miocene and Pliocene horizons farther south.

Marine Tertiary beds have been found at several localities on the shores of the Sea of Okhosk and of Kamchatka.[11] In Kamchatka these beds are said to rest conformably on a series of continental lignite-bearing deposits which are probably of Kenai age. Here, at least, there appears to be no evidence of the late Eocene or early Miocene period of folding. On the other hand some of the marine Tertiary beds of the Siberian coast were deformed probably during the period of diastrophism believed to be of late Pliocene age, which has been recognized in the St. Elias region of Alaska.

The salient features of Alaska Tertiary history are so far as known as follows: At the close of the Upper Cretaceous there was a general uplift and gentle warping in which the

[8] Schrader, F. C., A reconnaissance in Northern Alaska: U. S. Geol. Survey Prof. Paper 20, pp. 81-83, 1904.

Leffingwell, E. de K., The Canning River region, Northern Alaska: U. S. Geol. Survey Prof. Paper 109, pp. 129-130, 1919.

Dall, William H., Pliocene and Pleistocene fossils from Arctic Coast of Alaska, and the auriferous beaches of Nome, Norton Sound, Alaska: U. S. Geol. Survey Prof. Paper 125-C, pp. 23-37, 1920.

[9] Moffit, F. H., Geology of Nome and Grand Central Quadrangles: U. S. Geol. Survey Bull. 533, pp. 38 and 108-119, 1913.

[10] Opus cited, p. 24.

[11] Dall, Wm. H., A sub-tropical fauna in Arctic Siberia: Proc. U. S. Nat'l. Museum, Vol. XVI, pp. 471-478, 1893.

Bogdanowitch, Karl, Geologische Skizze von Kamchatka: Peth. Mitthl., vol. 50, pp. 59-221, 1904.

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major part of Alaska was involved. Previous to this movement much of the Yukon and Kuskokwim, and Copper River basins were submerged, and marine conditions of sedimentation prevailed. After the uplift Alaska was outlined in essentially its present form, though somewhat larger. A great drainage system was then developed in which the Kenai fresh water deposits were laid down. These deposits rest on the marine Cretaceous. with no striking unconformity. In late Eocene or early Miocene times a widespread crustal disturbance took place which affected all of Alaska but was greatly intensified in the Pacific mountains and especially along certain zones. These zones of profound folding appear to follow the axis of the older Mesozoic folding. The striking feature of this crustal movement is that the Kenai beds in one zone are profoundly folded while in another nearby parallel zone the beds are almost undisturbed. Thus we find the Kenai rocks of the Matanuska coal-field highly indurated, and folded and faulted, while in the Susitna Valley, 20 miles northwest, they are little consolidated and practically horizontal. Extending the section 50 miles northwest the Kenai consists of indurated beds involved in the great thrust faults of the Alaska Range.[12] Where the Kenai beds are folded intrusion of dioritic rocks are not uncommon, but where they are little disturbed, igneous rocks are absent.

The period of Eocene diastrophism was followed by slight transgressions of the sea along the Pacific margin of Alaska during Miocene and Pliocene times. In the latter epoch the Arctic coastal plain was also submerged. There was another period of diastrophism in late Pliocene times, but so far as records show it was limited chiefly to the region of the St. Elias Range. In the same province there is evidence of uplift in Pleistocene times, which was probably accompanied by block faulting.

[12] Brooks, Alfred H., The Mt. McKinley region: U. S. Geol Survey Prof. Paper 70, pp. 98, 111, 113, 1911.

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CORRELATION OF TERTIARY MARINE FORMATIONS OF THE WEST COAST OF NORTH AMERICA

By Bruce L. Clark, University of California, Berkeley

INTRODUCTION

The construction of a correlation table of the marine formations of the West Coast is a very difficult task. It will undoubtedly be a good many years before such a table will be satisfactory to everyone working in this field. None of the horizons have been adequately mapped and monographed and the consequence of this deficiency is that some of the most important problems are still unsettled.

The difficulties of correlation on the West Coast have been greatly increased by several factors which will be briefly discussed before considering the details of the Tertiary divisions recognized in this paper.

It is a noteworthy fact that at the present time the marine faunas living along the borders of the Pacific Ocean are distinctly separated into faunal or geographical provinces. In this respect the West Coast of North America is typical of the whole Pacific border. Very few marine molluscan species are common to the coasts of Southern California and Alaska. We find an almost equally distinct difference between the fauna found at the Isthmus of Panama and that found along the coast of Southern California. These three faunas, Panama, Southern California and Alaska, have practically nothing in common. Furthermore, some of the faunas in intermediate areas are almost equally distinct.

During Tertiary times there was a similar differentiation of the West Coast faunas into geographical provinces.[1] It is generally recognized that the Pleistocene and Recent times mark one of the maximum periods of emergence of all of the continents. While this is not true in so great a degree of all the periods of the Tertiary, it is well known that the North American continent was submerged only around its borders. During a large part of this time the Pacific and Atlantic oceans

[1] Smith, J. P., Climatic relations of the Tertiary and Quaternary faunas of the California region: Proc. Acad. Sci., 4th Ser., vol. 9, No. 4, pp. 123-173, 1919.

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were disconnected and the significant fact is that we find in the Tertiary faunas marked evidences of temperature zones. If the three faunas mentioned above belonged to a Middle Tertiary instead of the Recent epoch it would have been very difficult to establish contemporaneity. It is very possible, even probable, that the paleontologist would have placed the faunas in separate epochs unless they were found interfingering at some locality or localities.

The accumulating evidence seems to show that this temperature differentiation of the faunas on the West Coast had its effect even as far back as the Eocene. A study of the fauna of the upper Oligocene indicates a fairly definite zonal arrangement from north to south along the coast. This zonal arrangement of the faunas is even more evident in the comparison of the marine middle Miocene of Southern California with that from Middle California and this in turn with the faunas from the same horizon in Oregon and Washington. The middle Miocene of Southern California may be regarded as warm temperate. In Oregon and Washington the fauna show a more boreal aspect. The generic assemblage is very different and a very large proportion of the genera is so characteristic of the warm temperate faunas which are absent in the northern localities. In Middle California the little we know of this fauna seems to show that it is of intermediate character.

There has been much confusion and disagreement in the past as to the correct sequence of that part of the Tertiary section referred to the upper Miocene or Pliocene. The difficulties involved have undoubtedly been in very large part the result of temperature differentiation. The faunas changed their characteristics very rapidly from north to south and the northern faunas had very little in common with the southern.

The upper Miocene of California, the San Pablo series, is best represented in Middle California.[2] Beds of lower and middle San Pablo age are not found in Southern California nor have they been recognized in the northern part of the State. The Upper San Pablo or Santa Margarita horizon has a much wider distribution. The fauna obtained from the Santa Margarita and the middle and lower members of the San Pablo series in the vicinity of San Francisco Bay may be regarded

[2] Clark, B. L., Fauna of San Pablo Group of middle California: Bull. Dept. of Geology, Univ. California, vol. 9, No. 22, pp. 385-572, 1915.

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as approximately warm temperate. If these faunas were now living off the coast of middle California they would probably not be found south of the Santa Barbara County coast. This conclusion is reached by an analysis of the recent species in the faunas. The fauna of the Santa Margarita horizon as found in Southern California represents a warm temperate facies that is not present in the San Francisco area. There is a sufficient number of distinctive species common to the faunas of these two areas to establish their correlation but taken as a whole the faunas are very different.

In Washington another fauna has been found that appears to be upper Miocene in age. Just what part of the San Pablo series it represents has not been established. I refer to the Montesano formation described by Professor C. E. Weaver. The fauna of the Montesano formation, judging from the recent genera in the assemblage, is boreal.[3] The assemblage is very different from the more temperate faunas of the San Pablo in California. If the correlation of the Montesano formation with the San Pablo series is correct there is very marked temperature differentiation, a differentiation comparable to that in the Recent faunas of the coast of middle California and Alaska.

The faunas obtained from the marine Pliocene of the West Coast show in an even greater degree the effects of temperature differentiation between the north and the south. The great number of local names which have been given to the various sections now recognized as Pliocene, testifies to the difficulties of correlation. There were at least two major cycles of deposition during the Pliocene period on the West Coast. The faunas obtained from the lower and middle Pliocene of the southern part of California are warm temperate. The fauna obtained from the upper Pliocene of this region has a sub-boreal aspect in some localities and in other localities indicates temperate or even warm temperate conditions. Because of the lack of adequate knowledge of the stratigraphy and fauna of the Pliocene a satisfactory explanation of this differentiation has not been reached.

In the vicinity of San Francisco Bay the fauna of the middle Pliocene is sub-boreal. A very large proportion of the

[3] Weaver, C. E., Tertiary formations of Western Washington: Bull. 13, Washington Geol. Survey, pp. 1-299, 1916.

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recent species composing this fauna is now found in the sam area. As we go northward in our study of the Pliocene sec tions we find that the shallow water faunas become more an more boreal. A short distance south of San Francisco a middl Pliocene fauna shows the interfingering of the northern an southern species. I refer to the fauna of the type section o the Purissima in the Santa Cruz quadrangle.

In addition to the general change in temperature fron north to south, there was in the Tertiary still another facto which undoubtedly contributed to the differentiation of th invertebrate faunas. This factor was the existence of numerous partially isolated local basins of deposition.

The sediments of the Tertiary were for the most part laid down in geosynclinal troughs which paralleled the present Coast Ranges. The number and position of these troughs has varied through the different periods and epochs of deposition. Thus, here we had a condition which was similar to that which existed in the Appalachian geosyncline during the Paleozoic. Great thicknesses of clastic sediments, in aggregate exceeding forty thousand feet, were deposited on the West Coast during Tertiary time. These Tertiary basins either existed as large embayments or long inland seas, some of the latter of which were comparable in size to the Mediterranean and were probably as well if not more completely separated from the main ocean basin. These conditions produced marked local environments, with corresponding local changes in the faunas. It is very probable that the faunas in each basin derived certain peculiar characteristics due to isolation alone.

Still another factor that has brought about difficulties in correlation in West Coast Tertiary has been the rather general poor preservation of the fossil material. The Tertiary beds have been extensively folded and tilted and this deformation has resulted in the leaching of the original material of the shells, especially in the sandstones and shales. Intensive collecting will in time remedy this difficulty as well as bring to our knowledge a larger number of localities where the fossils are in a better state of preservation.

While the invertebrate faunas of the Tertiary and Recent have been so differentiated by temperature and land barriers that even local correlation is difficult by means of the fossil invertebrate faunas the great land mass offered favorable opportunities for a widespread distribution of the mammalian

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faunas. The discovery of land mammals in connection with the marine faunas is of great assistance in establishing the sequence. The correlation table (Table 1) is in part based upon such discoveries. The recognition of the position of the Miocene and Pliocene of Southern California was due to the association of marine and continental deposits.

In presenting a correlation table of this kind one of the first things that will be asked is the author's point of view in attacking the problems. The point of view accepted is that diastrophism is the ultimate basis for geological divisions. In other words the divisions recognized in this paper have been made on the basis of stratigraphic breaks which are believed to be more than local. It is also important to note that every stratigraphic unit thus recognized is also represented by a distinctive fauna, belonging to a distinct epoch of deposition.

TERTIARY DIVISIONS

There are at least five major divisions in the Tertiary of the West Coast, which in the writer's estimation should be recognized as representing true periods. Each one of these five major divisions is composed of more than one stratigraphic and faunal division, that is, more than one epoch of deposition. Each epoch is represented by a distinct fauna that lived in a distinct sea. The deposits belonging to each of these major divisions will be referred to as a series; thus, the Eocene, Oligocene, lower-middle Miocene, upper Miocene, and Pliocene series. To the deposits of each epoch of deposition the term "group" has been applied. The term "formation" is reserved for the lithologic member within the group.

EOCENE PERIOD

During the Eocene period on the West Coast there were at least three epochs of deposition as indicated in the correlation table and some information suggests that there may have been five. At the present time, however, only three distinct stratigraphic divisions have been definitely separated. These are the Martinez (lower Eocene), Meganos (middle Eocene) and Tejon (upper Eocene). Crustal movements of considerable magnitude occurred between each of these epochs. In the region of Mount Diablo, middle California, there is a marked difference in dip and strike between the Martinez and

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Meganos Groups and this is also true of the contact between the Meganos and Tejon. Over large areas up and down the coast where sections of the Meganos and Tejon deposits occur in contact there is an angular unconformity separating the two. The marine faunas of the three divisions of the Eocene differ greatly from each other, further substantiating the stratigraphic evidence of a marked hiatus.[4]

CORRELATION OF EOCENE DEPOSITS

The evidence for the correlation of the West Coast Marine Eocene with that of the Gulf and East Coast provinces and through them with Europe is based upon the identity of species or the presence of equally related forms common to the two regions. The evidence appears to be stronger for the correlation of the Meganos and Tejon (middle and upper Eocene) than for the lower or Martinez Group. There can be very little doubt but that during those epochs of time there was a direct connection between the Gulf of Mexico and the Pacific Ocean.

CLIMATE

The climate during the Eocene of the West Coast was subtropical or possibly warm temperate rather than tropical. The arkosic character of the Meganos deposits, a character very general on the West Coast, strongly suggests that we are dealing with deposits which were derived from an arid land mass, while the Tejon sandstones are at most localities in California composed almost entirely of pure quartz grains, indicating humid climatic conditions at that time.[5]

OLIGOCENE PERIOD

Accumulated evidence appears to show that there were two distinct cycles of deposition during the Oligocene on the West Coast. The two cycles are the Molopophrous lincolnensis and Acila gettysburgensis zones of Dr. C. E. Weaver. They will

[4] Dickerson, R. E., Fauna of the Martinez Eocene of California: Bull. Dept. Geol. Univ. California, vol. 8, No. 6, pp. 61-180, 1914; and Clark, B. L., The Meganos group, a newly recognized division in the Eocene of California: Bull. Geol. Soc. of Am., vol. 28, pp. 281-296, June 1918.

[5] Dickerson, R. E., Climatic zones of Martinez Eocene time: Proc. California Acad. Sci., 4th Ser., vol. 7, No. 7, pp. 193-196, 1917.

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be referred to as the Lincoln and San Lorenzo groups.[6] Recent field work of the author in Washington and Oregon has shown fairly conclusively that there were at least two distinct epochs of deposition in that region. The writer believes that this will prove to be the case in California when more detailed study on the stratigraphy of the Oligocene over wider areas has been completed. It is certain that the two faunas first differentiated in Washington are also represented in the same sequence in California and the Oligocene series may therefore be considered as being made up of two distinct epochs.

The aggregate thickness of the marine beds of the upper and lower Oligocene of the West Coast exceeds 10,000 feet. A large part of these sediments consists of shales and shaly sandstones.

CORRELATION

The evidence for the general correlation of the West Coast Marine Oligocene deposits is indirect. No invertebrate species or even apparently related forms have been recognized as common to the Oligocene of the West Coast and that of the Gulf province. The faunal evidence at hand seems to show that after the close of the Tejon epoch (upper Eocene) there was no direct connection between the Atlantic and Pacific Coast basins.

Dr. Ralph Arnold was the first to announce the presence of Oligocene in California. The type section of the San Lorenzo formation is in the Santa Cruz Mountains of the Santa Cruz quadrangle of California.[7] Dr. Arnold concluded that the San Lorenzo formation is of Oligocene age because of its stratigraphic position between beds generally recognized as upper Eocene and lower Miocene (Vaqueros). He also observed that the fauna of the San Lorenzo appeared to have both Eocene and Miocene affinities. Later studies of the faunas of the Lincoln and San Lorenzo horizons have borne out Arnold's

[6] Weaver, C. E., Tertiary formations of western Washington: Bull. 13, Washington Geol. Survey, pp. 1-129, 1916;

———Preliminary note on the paleontology of western Washington: Bull. 15, Washington Geol. Survey, pp. 1-80, 1912;

———Tertiary faunal horizons of western Washington: Pub. Univ. of Washington, vol. 1, No. 1, pp. 1-67, 1916.

[7] Arnold, Ralph, Tertiary and Quaternary Pectens of California: Prof. Paper, U. S. Geol. Survey, No. 47, 1906, and

Branner, J. C., Newsom, J. F. and Arnold, Ralph, U. S. Geol. Survey Folio, Santa Cruz Quadrangle, No. 163, p. 3, 1909.

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original conclusions.[8] At the time that Arnold did his work the Lincoln horizon had not been differentiated. The fauna of this horizon shows a much closer relationship to that of the Tejon (upper Eocene) than to that of the lower Miocene, while the fauna of the San Lorenzo horizon, equivalent to Weaver's Acila gettysburgensis zone, has a Miocene aspect, a fairly large number of the genera and species being common to the two.

CLIMATE

The temperate conditions during the Oligocene time were fairly uniform along the West Coast as far north as Alaska. The waters of the lower Oligocene, judging from the molluscan fauna, were sub-tropical to warm temperate, while those of the upper Oligocene were more temperate.[9] Thus the fauna of the San Lorenzo horizon (upper Oligocene) is more closely related to that living off the coast of California, Oregon and Washington at the present time than to that of the Lincoln.

MIOCENE PERIOD

The marine Miocene of the West Coast is divisible on the basis of stratigraphy and faunas into two major series, each of which contains minor stratigraphic and faunal divisions. That portion of the geological section referable to the marine lower-middle Miocene, contains two fairly distinct cycles of deposition, at least in certain areas in the State of California and constitutes the Monterey series. The lower of the two divisions of this series is the Vaqueros group, sometimes referred to as the Turritella inezana zone. The upper division is herein called the Temblor group and is represented by the fauna of the Turritella ocoyana zone.[10] The upper of the two major Miocene divisions is referred to as the San Pablo

[8] Clark, B. L., Occurrence of Oligocene in the Contra Costa Hills of middle California: Bul. Dept. Geol. Univ. California, vol. 9, No. 2, pp. 9-21, 1915;

San Lorenzo Series of middle California: Bull. Dept. Geol. Univ. California, vol. 11, No. 2, pp. 45-234, 1918, and

Clark, B L. and Arnold, R., Marine Oligocene of the West Coast of North America: Bull. Geol. Soc. Am., vol. 29, pp. 297-308, 1918.

[9] Dickerson, R. E., Climate and its influence upon the Oligocene faunas of the Pacific Coast: Proc. California Acad. Sci., 4th ser., vol. 7, No. 6, pp. 157-192, 1917.

[10] Smith, J. P., Geological range of Miocene invertebrate fossils of California: Proc. California Acad. Sci., 4th ser. Geol., vol. 3, pp. 161-182, 1912.

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series. This series is composed of three minor stratigraphic and faunal divisions, the Briones, Cierbo and Santa Margarita groups. As will be pointed out later each one of these minor divisions represents a distinct cycle of deposition and has a fairly distinctive fauna.

MONTEREY SERIES

The deposits of the Vaqueros sea covered a much more limited area than those of the Temblor. The question as to the distinctiveness of the Vaqueros and Temblor, that is to say, whether or not they represent several stratigraphic units, has been the source of considerable disagreement in time past.[11] Nearly everyone, however, who has studied the faunas obtained from these beds has agreed that they are fairly distinct, one being the Turritella inezana zone, the other, the Turritella ocoyana zone.

Recent stratigraphic and paleontological work, the results of which are still unpublished,[12] appear to show that at certain localities in California there were crustal movements of considerable magnitude between the deposition of the Vaqueros and Temblor. The writer believes that the proper valuation of this unconformity is still open to question. The faunas are, however, fairly closely related and it is because of the obscure stratigraphic relations at various localities and the similarity of the faunas that the formations have generally been thrown together. The United States Geological Survey, in their more recent publications on the Coast Range geology apply the name Monterey group to this series of deposits. In the writer's opinion the Monterey is a series rather than a group and is composed of two epochs, the Vaqueros and the Temblor.

RELATIONS OF THE MONTEREY SERIES TO THE UPPER OLIGOCENE

There is no conclusive evidence of crustal movements subsequent to the deposition of the San Lorenzo and previous

[11] Louderback, G. D., Monterey series of California: Bull. Dept. Geol. Univ. California, vol. 7, No. 10, pp. 177-241, 1913, and

Martin, Bruce, Fauna of the type locality of the Monterey series in California: Bull. Dept. Geol. Univ. California, vol. 7, No. 7, pp. 143-150, 1912.

[12] Note: Mapping by Dr. Kew of the U. S. Geol. Survey shows an important unconformity in southern California between the Temblor and the Vaqueros. Mr. Wayne Loell, formerly of Leland Stanford University, is working on a monograph of the Vaqueros fauna and believes that the Vaqueros and Temblor represent two distinct horizons.

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to the deposition of the Vaqueros. However, that there was an important hiatus following the deposition of the beds of these two horizons is brought out in a comparison of the faunas. Very few of the species of the San Lorenzo horizon are found in the Vaqueros while on the other hand a very large percentage of the species of the latter horizon are apparently common to the Temblor. It is this great faunal change in going from the San Lorenzo to the Vaqueros horizon that is most indicative of one of the major breaks. Furthermore, the distribution of the beds representing these two horizons is very different and is important evidence in support of the view that there is a major break between them.[13]

CORRELATION OF THE TEMBLOR AND THE VAQUEROS

As is the case of the Oligocene, very little direct evidence has been obtained for the correlation, on the basis of the invertebrates, of the divisions of the Monterey series with the lower-middle Miocene of the eastern province and of Europe. The deposits of the Monterey series were first referred to the Miocene by Conrad[14] as early as 1849. This determination was made chiefly on the general similarity of the generic assemblage to the fauna of the Atlantic Coast Miocene. Following Conrad, the beds of the Monterey series were determined as Miocene by Whitney and Gabb, both of the old California State Geological Survey. No attempt was made by these pioneers to recognize any subdivisions in the Miocene. Beds now recognized as upper Miocene (San Pablo) were called Pliocene by Whitney and Gabb.[15]

The first announcement of a correlation which gave a fairly definite position to the Temblor group appeared in a paper by Professor J. C. Merriam.[16] Previous to this the Temblor had been referred by certain geologists to the lower Miocene and by others to the Oligocene. In the region of North Coalinga the land formation locally known as the Big Blue was found intercalated with beds of Temblor age from

[13] Clark, B. L., San Lorenzo series of Middle California: Bull. Dept. Geol. Univ. California, vol. 11, No. 2, p. 105, 1918.

[14] Conrad, T. A., Fossils from northwestern America: Geol. U. S. Expedition, vol. 1., app., pp. 723-29, 1849. Proc. Acad. Nat. Sci. Philadelphia, vol. 7, p. 441, 1831.

[15] Gabb, W. M., California Geol. Survey, Paleontology, vols. 1 and 2, 1864-1869.

[16] Merriam, J. C., Tertiary vertebrate faunas of the North Coalinga region of California: Trans. Am. Philos. Soc., vol. 22, Pt. 3, pp. 1-44, 1915.

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which a good marine fauna has been obtained. The beds in the Coalinga field mapped as Vaqueros by the United States Geological Survey belong to the Temblor horizon. The deposits known as the Big Blue were first considered by Arnold and Anderson[17] as a part of the Santa Margarita (upper Miocene). Later mapping, however, showed that the Big Blue is more closely connected with the Temblor (the so-called Vaqueros) than to the Santa Margarita of that section.[18]

In describing the fauna obtained from the Big Blue, Merriam says:

> In terms of the vertebrate series of western North America the fauna of the Merychippus zone in the North Coalinga region is clearly earlier than the lower Miocene and not later than upper Miocene. The fact that the Big Blue comes in a section where the Temblor deposits are very thin, and we think are only the top of that section, makes it seem reasonable to believe that the Temblor deposits as a whole belong to the middle Miocene rather than to a part of the upper Miocene.

A clue to the age of the Vaqueros deposits was obtained very recently by the discovery, near the south end of the San Joaquin Valley, of land-laid deposits intercalated with marine beds of Vaqueros age. Beds below these land-laid deposits and the marine beds immediately above are believed to represent the same horizon. The announcement of the discovery of a vertebrate fauna from these land-laid beds was recently made by Dr. Chester Stock.[19] These continental beds, referred to as the Tecuja Beds, were tentatively correlated by Dr. Stock, with the John Day horizon of Oregon. He reports the presence of Hypertragulus, a form related to the early camels and deer. Hypertragulus occurs both in the upper Oligocene and the lower Miocene but the species from the Tecuja beds seems to be more closely related to the John Day form (upper Oligocene) than to that found in the lower Rosebud (lower Miocene) of the Great Basin province. While Dr. Stock has indicated the relationship of the Tecuja vertebrate fauna to that

[17] Arnold, R. and Anderson, R., Geology and Oil Resources of the Coalinga District of California: U. S. Geol. Survey Bull. 396, pp. 3-169, 1909.

[18] Anderson, F. M., and Martin, B., Neocene record of the Temblor Basin, California and Neocene deposits of the San Juan District, San Luis Obispo County, Proc. California Acad. Sci., 4th ser., vol. 4, pp. 15-112, 1914.

[19] Stock, Chester, An early Tertiary vertebrate fauna from the southern Coast Ranges of California: Bull. Dept. Geol. Univ. California, vol. 12, No. 4, pp. 267-276, 1920.

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of the John Day he has also stated that it may occupy a position in the Tertiary transitional between the Oligocene and Miocene. It seems to the writer that the stratigraphic and paleontologic evidence favors the lower Miocene age of these beds rather than the upper Oligocene. The most important evidence in favor of this last conclusion is that the invertebrate fauna of the Vaqueros is very closely related to that of the Temblor, a very large percentage of the species being common to these two faunas. Some of the forms listed are types of considerable ornamentation and complexity and are generally known to have a fairly short geological range. On the other hand, the known fauna of the Vaqueros is very different from the known fauna of the San Lorenzo and a great faunal break occurs between the San Lorenzo and the Temblor. In the section at the south end of the San Joaquin Valley where the Tecuja beds occur. the Vaqueros rests directly upon the San Lorenzo.

SAN PABLO SERIES

The San Pablo series is recognized as the second major division of the Miocene. Like the San Lorenzo and Monterey series, the San Pablo is divisible into minor units on the basis of stratigraphy and faunas. The faunal changes and disconformable relationships of the beds indicate that the sea advanced and retreated three times in middle California during this period. It is only in middle California that we find the complete sequence of the upper Miocene series. The two lower divisions of the San Pablo series, the Briones and the Cierbo groups,[20] have been recognized only in this general area.

STRATIGRAPHIC RELATIONS

In certain sections immediately east of or in the Salinas Valley, a distance of not more than one hundred miles from the San Francisco Bay area, we find evidence of crustal movements between the Temblor and the Santa Margarita which have been

[20] The use of the term San Pablo for the upper Miocene series of deposits on the West Coast makes it necessary to dispense with the term San Pablo within the group. The name Cierbo will therefore be used in this paper in referring to the middle group of the San Pablo series. The type section of the Cierbo is on the south side of the Canada del Cierbo near Carquinez Straits. Santa Margarita is a name in common use for the upper portion of the section in the southern part of the state of California and will be applied as a general name for the upper member of the San Pablo.

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described as mountain making. In the Salinas Valley region it is not uncommon to find the difference in dip between the Temblor and the Santa Margarita as much as 30 or 40 degrees or even more, together with marked difference in strike. Dr. Arnold, in describing the movements that caused this unconformity, says:[21]

One of the widespread and important periods of diastrophism in the Tertiary history of the Pacific coast was that immediately following the deposition of the Monterey or lower middle Miocene. Its effects are visible from Puget Sound to southern California. It is marked as much by readjustment, by local faulting and folding as by general movements of elevation and subsidence. In some regions the folding and faulting were intense, the greatest disturbances accompanying the uplift of the mountain ranges to an altitude of thousands of feet. In other regions low broad folds were formed during the post-Monterey disturbance, and the strata were not upheaved to a great altitude. Faulting on a most magnificent scale took place along the earthquake rift and certain other fault-zones, especially that in the Salinas Valley, and along these lines of displacement, masses of granite rocks, which during the preceding epoch had been subject to little or no erosion, were suddenly thrust upward and left exposed to the ravages of streams that assumed the proportions of torrents in certain regions, as for instance adjacent to the Carrizo Plain in south-central California. The post-Monterey diastrophic movements in the Puget Sound province also produced sharp relief as is evidenced by the coarse sediments immediately following the disturbance. The localization of movements during the period is exemplified at numerous localities in the Coast Ranges.

Throughout much of the coastal belt, and probably likewise in the interior, great volcanic activity took place during the middle Miocene, this being the last epoch of volcanism in the Coast Ranges, south of San Francisco Bay.

It is interesting to note that only a comparatively short distance to the east of the southern Salinas Valley area where the great unconformity between the Temblor and the Santa Margarita deposits is best seen, that it has been very difficult to find the line separating these two horizons. Both the Santa Margarita and Temblor deposits in the southwestern part of the San Joaquin Valley are composed of organic shales and in consequence of the difficulty in separating the two horizons the United States Geological Survey has applied the name Maricopa shale to the deposits as a whole. No marked stratigraphic break has been found in middle California between the deposits of the lower San Pablo series (the Briones group) and those

[21] Arnold, Ralph, The environment of the Tertiary faunas of the Pacific coast of the United States: In outlines of geology, Willis and others, p. 226, 1910.

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representing the Temblor. Here the beds of these two horizons are parallel, the chief basis for making the separation being irregular contacts and the difference between the faunas. Thus in this part of the State of California we have no evidence of crustal movements having taken place immediately after the deposition of the Temblor beds.

CORRELATION

Direct evidence for the correlation of the San Pablo series with the eastern and European sections is lacking. The writer has presented the evidence for the correlation of this group in a former paper.[22] The correlation is based upon an analysis of the fauna by the percentage method and the evidence afforded by the occurrence of vertebrates in beds immediately above and below the San Pablo. The following quotations are taken from the above-mentioned paper:

> The percentage of Recent molluscan species in the San Pablo of middle California as listed by the writer is 23 plus; as based upon the gastropods the percentage is only 11 per cent. If we use the percentages as applied to the east coast Neocene and if we can rely upon the equal refinement in the determination of the species, the San Pablo may be considered to be upper Miocene in age, possibly lower Pliocene.
>
> Probably the best evidence showing the age of the uppermost beds of the San Pablo of middle California comes from vertebrate material obtained in the fresh-water beds which in middle California overlie unconformably the San Pablo group. This material was described by Professor J. C. Merriam in his paper "Vertebrate Fauna of the Orindan and Siestan Beds in middle California." [Bull. Dept. Geol., Univ. California, vol. 7, 1913.] His conclusions as to the age of these beds as shown by the vertebrates are as follows: "The mammalian remains known from both the Orindan and Siestan up to the present time all represent forms such as might be expected in the late Miocene or in the earliest Pliocene, but it will be necessary both to have better material from the Orindan and Siestan and to have well-known faunas of western Miocene and Pliocene for comparison before the last work on the age determination can be pronounced.
>
> "Considering the indefiniteness of all the factors concerned one would not seem justified in being more definite than to state that the Orindan and Siestan faunas are near a late Miocene stage. When the faunas of the two formations are better known, it may appear that more than one stage is represented."

The reader will remember from the discussion of the age of the Vaqueros that the vertebrate fauna obtained from the

[22] Clark, B. L., The fauna of the San Pablo group of middle California: Bull. Dept. Geol., Univ. California, vol. 8, No. 22, p. 339, 1915.

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Big Blue formation which is perhaps intercalated with the Temblor deposits in the region to the north of Coalinga was determined by Dr. J. C. Merriam as being not later than middle Miocene. In the same section the Santa Margarita formation is found unconformably above the Big Blue and marine Temblor beds. Also, as will be brought out in a discussion of the Pliocene, a lower Pliocene vertebrate fauna was found in land-laid beds resting unconformably upon the Santa Margarita formation. Thus it would seem that if we can trust the correlation on the basis of the vertebrates there can be very little doubt as to the age of the Santa Margarita group which comes between beds containing these vertebrate faunas, one not earlier than middle Miocene, the other not later than lower Pliocene.

PLIOCENE PERIOD

The marine Pliocene of the West Coast as now recognized is divisible into at least three stratigraphic units, the Jacalitos, Merced and the Saugus. Continental deposits are found in different parts of the Coast Ranges representing all three of these horizons and in some instances, to which reference has already been made, these continental deposits are found closely associated with the marine beds.

The crustal movements which occurred between the deposition of the Santa Margarita group and the Jacalitos were not as great as those that occurred between the Temblor and Santa Margarita groups. However, it must be remembered that the evidence for the latter unconformity is found throughout a comparatively limited area and where it is best developed the Briones and Cierbo groups are absent. It may well have been the result of folding which was going on from the close of the Temblor to the close of the Briones and therefore very probably represents a much longer lapse of time than that between the Santa Margarita and the Jacalitos (lower Pliocene). Dr. Nomland's study of the Santa Margarita and Jacalitos faunas has shown that the hiatus between these epochs was more than local.[23]

[23] Nomland, J. O., Fauna of the lower Pliocene at Jacalitos Creek, California: Bull. Dept. Geol., Univ. California, vol. 9, No. 14, pp. 199-214, 1916;

Nomland, J. O., Fauna of the Santa Margarita beds in the north Coalinga region of California: Bull. Dept. Geol., Univ. California, vol. 10, No. 18, pp. 293-326, 1917.

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The fauna of the Jacalitos (lower Etchegoin) is very distinct from that of the Santa Margarita (upper San Pablo). None of the highly ornamented gastropods, pelecypods or echinoids have been found common to the two horizons. The percentage of recent species in the Santa Margarita is much less than in the Jacalitos of Nomland.

In 1893, Dr. A. C. Lawson named and described the section of Pliocene deposits occurring on Seven Mile Beach, San Francisco Peninsula, a few miles south of the Golden Gate. The Merced series, as the deposits were named, is well exposed along the sea-cliff at this locality and exceeds 5800 feet in thickness. This series is equivalent to the lower and middle Pliocene deposits in other parts of the Coast Ranges.[24]

What is probably the largest and most important stratigraphic break in the marine Pliocene is found in the Fernando series in the region just north of Los Angeles, Los Angeles County.[25]

Over a fairly large area in that region there is a marked difference in dip and strike between the lower and middle Fernando (now referred to as the Pico formation)[26] and what has been previously referred to as the upper Fernando. The beds of this upper horizon contain a very large percentage of Recent species. The Geological Survey proposes to use the name Saugus formation for the upper part of the Pliocene. It is herein referred to as the Saugus Group. The faunal break between the Saugus and the Pico is very great and indicates a great lapse of time. Indeed, the difference is so great that the question may be raised as to whether the Saugus does not

[24] Lawson, A. C., The Post-Pliocene diastrophism of the coast of Southern California: Bull. Dept. Geol., Univ. California, vol. 1, No. 4, pp. 115-160, 1893: San Francisco Folio: U. S. Geol. Survey, No. 163, p. 13; and Sketch of the Geology of the San Francisco Peninsula: U. S. Geol. Survey, 15th Ann. Rept., pp. 399-476, 1893-4.

[25] Eldridge, G. H., and Arnold, R. N., Santa Clara Valley, Puente Hills and Los Angeles Oil Districts of California: Bull. 309, U. S. Geol. Survey, pp. 1-259, 1907.

Arnold, R., and Anderson, R., Geology and oil resources of the Santa Maria District, California: U. S. Geol. Survey Bull. 322, pp. 1-157, 1907.

Kew, W. S. W., Structure and oil resources of the Simi Valley, southern California: Bull. 691 M, U. S. Geol. Survey, pp. 323-355, 1919.

[26] The name Pico formation has been used by the U. S. Geol. Survey in a still unpublished work, for deposits formerly referred to as the lower and middle Fernando. The Pico and Saugus formations comprise the Fernando group in Ventura County in the U. S. Geol. Survey nomenclature.

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belong to the Pleistocene rather than to the Pliocene. If so, the West Coast Pleistocene formations have been generally folded.

CORRELATION

There has been considerable confusion in the past as to the proper sequence of the Pliocene. The reasons for this confusion appear to be due to two factors: first, the basins of deposition during the Pliocene were more local and isolated than they had been during previous periods, and second, temperature conditions varied radically from one locality to another. It is very probable that both of these factors contributed to the great differentiation observed in the faunas of the various provinces but the writer believes that the latter factor, temperature condition, was the most important. The great confusion as to the proper sequence of the numerous formations referred to the Pliocene is reflected in the many names which have been given to these beds. Beginning in Oregon we have the "Empire" formation; in northern California, the "Wild-cat;" in the region of San Francisco Bay, "the Merced," and a little to the south of this, the "Purissima." The "Jacalitos" and "Etchegoin" formations occur in the Coalinga region, and the "Fernando" and "Saugus" in the Ventura district. Still farther to the south are the "San Pedro Pliocene" and the "San Diego Pliocene" sections. Certain of these formations, the "Purissima," "Jacalitos," and "Etchegoin" have in the past been correlated with the San Pablo upper Miocene of middle California.

During the last few years our ideas of the sequence of these formations have been radically revised as a result of detailed studies of the faunas. The writer's study of the San Pablo series has convinced him that the faunas of that series belong to an older horizon than those of the Jacalitos-Etchegoin, Purissima and Pico, judging from the percentage of recent species in the latter beds. Later work by Dr. Nomland on the Jacalitos-Etchegoin in the Coalinga region seems to corroborate this conclusion. The most conclusive data we have indicating the Pliocene age of these formations are the fossil land vertebrates in the so-called Jacalitos-Etchegoin of the Coalinga district. The vertebrate remains were obtained from three distinct horizons, one, in what had been mapped as Jacalitos, a second, in the middle of the type section of the Etchegoin and the other at the top of the Etchegoin. Professor J. C. Mer-

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riam, to whom this material was referred for study, has determined these faunas as of Pliocene age. The lowest fauna, the Neohipparion zone, Dr. Merriam referred to as being not older than lower Pliocene. The second horizon is well up in the Pliocene and the fauna from the upper Etchegoin is referred to as the Pliohippus proversus zone and is of the upper Pliocene age. It is interesting to note that stratigraphically above the uppermost Pliocene fauna in the same section, there are several thousand feet of land-laid deposits which are folded and are older than the Pleistocene terraces of that region. No definite evidence, however, has been obtained from these upper beds to indicate their exact position, but it is suggested that they may be the land-laid equivalent of the Saugus of that vicinity. One of the most interesting results of the study of the invertebrate faunas of the Pliocene is the evidence of temperature differentiation. The fauna of northern and middle California (including the faunas of the Wild-cat and Merced) are essentially boreal in character. In the southern part of California the Pliocene is, for the most part, represented by a fairly warm temperate fauna. These two faunas, the boreal and warm temperate, have very little in common and consequently it was a long time before their contemporaneity was recognized. The solution of the problem was obtained from the fauna of an intermediate area. The fauna of the type section of the Purissima in the Santa Cruz Mountains is in part boreal and in part warm temperate. Certain species very common in the north were found in this section in beds with species also found in southern faunas, some of the forms being fairly highly ornamented. A very great deal of work still remains to be done in detailed studies of the Pliocene faunas but we now feel certain that we can recognize two general horizons, the Merced and the Saugus. More detailed studies of these faunas may lead to further subdivision of these groups.

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CORRELATION OF THE TERTIARY FORMATIONS OF CENTRAL AMERICA AND THE WEST INDIES

By T. Wayland Vaugan

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Introduction

Because during a considerable part of Tertiary time there was marine connection between the Atlantic and Pacific oceans across the site of what is now Central America, the Caribbean region is critical in the solution of problems of geological correlation in the Pacific region. Long ago J. Carrick Moore[1] quoted Sowerby as authority for the resemblance of many of the fossil shells from Santo Domingo to Recent species inhabiting the seas of China, Australia, and even the western coast of America.[2] P. Martin Duncan noticed a similar resemblance among the corals,[3] and said:

> The presence of species of Alveopora, Stylophora, Flabellum, Placotrochus, Rhodaraea, Astroria, Coeloria, etc., in the raised coral formations must refer to a different condition of the physical circumstances of the West Indian seas from that now existing, and to those peculiarities

[1] J. Carrick Moore, On some Tertiary beds in the Island of San Domingo: from the notes of J. S. Heniker, Esq., with remarks on fossils: Geol. Soc. London Quart. Jour., vol. 6, pp. 39-44, 1850.

[2] Op. cit., p. 43.

[3] Duncan, P. Martin, On the fossil corals of the West Indian Islands: Pt. I: Geol. Soc. London Quart. Jour., vol. 19, pp. 407-458, pl. 13-16, 1863.

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of climate, of sea-depth, purity and force of sea, and of coast-line, which are noticed in the ocean between eastern Africa, and America. It is worthy of notice that, at the present time, the Australian, Pacific, and Indian Ocean corals differ as a rule in species and often in genera, that the nearest coral-reef is hundreds of miles to the west of the Isthmus of Panama, and that the corals of the Atlantic are few and far between; yet the existing coral provinces are all represented in the Miocene beds now under consideration.[4]

During recent years the volume of information on this subject has rapidly increased. For instance, M. A. Howe (1919, **2**, p. 11) states that *Archaeolithothamnium affine* M. A. Howe from the middle Oligocene of Antigua has its closest relative in *A. sibogae* A. Web. and Fosl. of the region of the Sulu Archipelago, Borneo, and Celebes. Many species of foraminifera fossil in Central America, the West Indies, or the southeastern United States find their nearest living relatives in the Indo-Pacific region. Regarding the foraminiferal fauna of the lower Oligocene Byram calcareous marl of Mississippi, Cushman (1920, **6**, **7**) says: "Its fauna shows that the larger proportion of the species are closely related to or identical with those now living in the general Indo-Pacific region." Species now living in the Indo-Pacific are *Textularia folium* Parker and Jones, *Bolivina amygdalaeformis* H. B. Brady, *B. nitida* H. B. Brady, Parker and Jones, *Hauerina fragilissima* H. B. Brady. The evidence supplied by the foraminifera might be greatly increased; for example, Operculina, a genus abundantly represented in the upper Eocene and Oligocene and present in the Miocene of the Caribbean region (Cushman, 1921, **5**)[5] is now extinct in the Atlantic Ocean but is common in the tropical western Pacific.

The corals have been shown by my own work to possess greater affinities with Indo-Pacific faunas than Duncan recognized (Vaughan, 1917, **1**; 1919, **4**). For instance genera not recognized by Duncan in his study of the West Indian corals that at present occur in the Indo-Pacific but not in the Caribbean region are Galaxea, Pavona, Leptoseris, Haloseris, Diploastrea, Astreopora, and Endopachys. Jackson has found similar relations among some of the echinoids (1921, **3**); and Maury (1917, 2, pp. 421-422) and Vaughan and Woodring, (1921) and Woodring (no date, **2**) have added to the knowledge of molluscan genera that are common to the Caribbean Tertiary and the living Indo-Pacific molluscan faunas. Among

[4] Op. cit., pp. 455-456.
[5] See bibliography at end of paper for complete reference.

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the Crustacea the genera Ranina, Scylla, and Podophthalmus are represented in the Antillean Tertiary formations but are now known living only in the Indo-Pacific region.

The facts above enumerated indicate the importance of the fossil faunas of the Caribbean region in the study of the biological history and geological correlation of both the Atlantic and Pacific basins.

STANDARD SECTIONS OF TERTIARY FORMATIONS IN EUROPE

The accompanying correlation table, Table 1, has been compiled by Dr. Julia A. Gardner for those areas in Europe which need to be particularly considered in the correlation of the Tertiary formations in the West Indies and Central America. As a part of the correlation of the middle American region is made by steps through the southeastern part of the United States to the middle Atlantic slope of the United States and thence to Europe, columns are included in the European table for England, Germany, and the Low Countries.

STANDARD SECTIONS OF TERTIARY FORMATIONS IN SOUTHEASTERN UNITED STATES

The correlation table, Table 2, herewith presented, indicates the present status of information on the correlation of the Tertiary formations in the region indicated by the above heading. With reference to the exposures of the Tertiary formations, particularly in the eastern Gulf Coastal Plain, there is probably no other part of the world in which there is a more complete succession of strata. The basal member of the system rests with a clear-cut disconformity on Upper Cretaceous strata. This disconformity, which represents a very considerable time interval, has been described in considerable detail by L. W. Stephenson in the paper cited below.[6] From the base of the Eocene up to and including the Byram calcareous marl at the top of the lower Oligocene there is no stratigraphic break except that the intercalation of lignitiferous horizons indicates that there were oscillations in the position of the strandline. Some of these oscillations have been described by Berry.[7]

[6] Stephenson, L. W., The Cretaceous-Eocene contact in the Atlantic and Gulf Coastal Plain: U. S. Geol. Survey Prof. Paper 90, pp. 155-182, pls. 11-19, text-figs. 13-20, 1915.

[7] Berry, E. W., Erosion intervals in the Eocene of the Mississippi Embayment: U. S. Geol. Survey Prof. Paper 95, pp. 73-82, text-figs. 27-31, 1915.

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The relations of the uppermost member of the lower Oligocene as exposed in Mississippi and Alabama to the middle Oligocene basal member of the Chattachoochee formation as exposed on Flint River, Ga., are not quite clear, because in the exposure on Flint River a middle Oligocene coral reef rests upon the eroded surface of the upper Eocene Ocala limestone. lower Oligocene strata being absent or represented only by fragments. But beginning with the middle Oligocene coral reef mentioned there is no stratigraphic break in the section until the top of the lower Miocene Alum Bluff formation is reached. At Alum Bluff, Apalachicola River, and at Jackson Bluff, Ocklockonee River, both localities in Florida, the upper Miocene, Choctawhatchee formation rests upon the distinctly eroded surface of the Alum Bluff, deposits of middle Miocene age being absent. On Savannah River, at Porter's landing. Georgia, however, a thin deposit of middle Miocene age, the Marks Head[8] marl, intervenes between the lower Miocene Alum Bluff formation and the upper Miocene Duplin marl.

Marine Pliocene is represented in Florida by the richly fossiliferous Caloosahatchee marl and the less fossiliferous Nashua marl.

All of these members of the Tertiary system are fossiliferous and although the biological characterization of each horizon is not yet complete so much work has been done that the more salient biological characteristics of each division are known. The different groups of organisms and the principal investigators who studied them are as follows: The fossil plants by Berry in a series of monographs; the fossil Foraminifera of the Miocene and Oligocene, but not yet of the Eocene below the Ocala limestone by J. A. Cushman; the fossil corals by myself; the fossil echinoids by Clark and Twitchell; the Mollusca by a large number of investigators, among whom will be mentioned Lea, Conrad, Aldrich, Dall, G. D. Harris, and Julia A. Gardner; and the bryozoa by Canu and Bassler,[9] who have published one of the most comprehensive monographs on American paleontology, and a volume by the same authors on the later Tertiary

[8] Vaughan, T. W., The Miocene horizons at Porter's landing, Georgia: Science, N. S., vol. 31, pp. 833, 834, 1910. Also in Veatch, Otto, and Stephenson, L. W., Preliminary report on the geology of the Coastal Plain of Georgia: Georgia Geol. Survey Bull. 26, pp. 364-369, 1911.

[9] Canu, F., and Bassler, R. S., North American early Tertiary Bryozoa: U. S. Nat. Mus. Bull. 106, pp. xx+879, 279 text-figs., and volume of 162 pls., 1920.

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AGE OF DEPOSITS		…	…	MISSISSIPPI	LOUISIANA
PLIOCENE		Wa…	…on	Citronelle formation	Citronelle formation
MIOCENE	upper	Du… Un…		Pascagoula clay	Pascagoula clay
	middle				
	lower		…ttiesburg …ay	Hattiesburg clay	Hattiesburg clay
OLIGOCENE	upper, middle		…ahoula …ndstone	Catahoula sandstone	Catahoula sandstone
	lower		…estone …n lime- …)	Vicksburg group: Byram calc. marl; Marianna limestone (with Glendon limestone and Mint Spring calcareous marl members)	Vicksburg limestone
				Vicksburg group: Red Bluff clay	
EOCENE	upper	Ca… st… Tr…	…kson …rmation	Jackson formation (with Yazoo clay member and Moodys calc. marl member)	Jackson formation
	middle			Claiborne group: Yegua formation	Claiborne group: Yegua formation
			…ion	Claiborne group: Lisbon formation	Claiborne group: St. Maurice formation
			…rstone	Claiborne group: Tallahatta buhrstone	
	lower		…formation …n …mation …nation	Wilcox group: Grenada formation; Holly Springs sand; Ackerman formation	Wilcox formation
			…tion …lay	Midway group: Tippah sandstone of Lowe; Porters Creek clay	Midway formation
			…one	Midway group: Clayton limestone absent or replaced by sand	

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bryozoa has been completed and is awaiting publication. The fossil Crustacea have not been studied.

From the foregoing brief statement it will be clear that knowledge of both the stratigraphy and of the biological characteristics of the Tertiary formations in the southeastern United States has reached a stage at which biological comparison with other regions are practicable.

One of the important recent advances in the knowledge of the relations of the Tertiary formations in the southeastern Coastal Plain was made by C. W. Cooke in his paper entitled "The age of the Ocala limestone" (Cooke, 1915, **1**), in which he showed that the Ocala limestone is of Eocene age and is the Floridian correlative of the Jackson formation of Mississippi. The Ocala limestone is one of the Coastal Plain formations that may be directly correlated with formations in Central America and the West Indies; for example, in the Brito formation of Nicaragua three species of Orthophragmina are known, and of these two occur in the Ocala limestone (Cushman, 1920, **4**, p. 39). The correlation of the Ocala limestone with the St. Bartholomew limestone of the Island of St. Bartholomew on the basis of large stellate species of Orthophragmina, O. antillea Cushman (Cushman, 1919, **3**, p. 55), is convincing. There are other tie-points between the geological section in the southeastern Coastal Plain and the West Indies and Central America, but they need not be mentioned at this place.

With regard to the correlation of the Coastal Plain section with Europe this matter is discussed by me (1919, **5**) and by Woodring and me (1921). The correlation in its general features appears to be trustworthy as the different lines of evidence are accordant, except perhaps the correlation of the Chesapeake group of Virginia and Maryland, which involves the correlation of the middle Miocene of the southeastern Coastal Plain. Berry on the basis of a few fossil plants expressed the opinion that the Chesapeake deposits are of Tortonian age,[10] whereas the marine invertebrates indicate Helvetian age. In correlation Table No. 2 the evidence of the marine invertebrates is followed, but in my paper (1919, **5**) I followed the evidence of the small fossil flora. Berry in his paper on the

[10] Berry, E. W., Physical conditions indicated by the flora of the Calvert formation: U. S. Geol. Survey Prof. Pap. 98, pp. 61-73, pls. 11, 12, 1916.

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Tertiary formations of western South America [printed in these Proceedings] follows the indications of the fossil flora.

STANDARD SECTIONS OF TERTIARY FORMATIONS IN CENTRAL AMERICA AND THE WEST INDIES

There have been very few at all comprehensive, adequately characterized sections of Tertiary formation described in Central America and the West Indies. The most comprehensive is that in the Dominican Republic, the description of which by Vaughan, Cooke, and others (1921) is now in press, but another section that includes a considerable range of strata is the one in the Panama Canal zone. The strata in the Republic of Haiti include deposits of Eocene, Oligocene, and Miocene age and a report describing them is in preparation by W. P. Woodring, J. S. Brown, and W. S. Burbank,[11] but the data contained in it are not yet available for general use. There are sections of considerable ranges of strata in Jamaica, Cuba, and Trinidad, but the information on them is fragmentary. The Tertiary strata in Porto Rico appear to be only of Oligocene and Miocene age, and a satisfactory classification of the deposits is not yet available in print. On many of the smaller West Indian islands deposits of only one horizon are well developed and these must be stratigraphically placed by reference to some standard section in the region or by general geological and paleontological considerations. Where fossils are abundant this can usually be done in a satisfactory way, and several of the isolated occurrences offer the best types for the subdivisions of the different Tertiary series.

PANAMA

The section as described for Panama by MacDonald (1919, p. 528) is as follows:

SUCCESSION OF BEDDED ROCKS IN THE PANAMA CANAL ZONE

(After D. F. MacDonald)

Late Pleistocene	11. Pleistocene formation	c. River alluvium b. Muds and silts a. Gravel
Pliocene	10. Toro limestone	Shell and marl limestone

[11] To be published by the Department des Travaux Publics de la République d'Haiti.

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Oligocene	9. Panama formation	Light colored tuff beds, argillite, etc.
	8. Gatun formation	c. Clay beds b. Fine sandstone a. Argillite
	7. Caimito formation	c. Sandstone b. Limey conglomerate a. Sandstone
	6. Emperador limestone	Marine limestone, many corals
	5. Cucaracha formation	Land formed clay rocks, lava flow, etc.
	4. Culebra formation	Marine carbonaceous shale, clay, tuffs, limey sandstone
Eocene?	3. Bohio[12] conglomerate	Coarse and fine conglomerate and sandstone beds
	2. Las Cascadas agglomerate	Volcanic debris, mud-lava, some flows and dikes of andesite
	1. Bas Obispo formation	Volcanic breccia

The Culebra formation, the Emperador limestone, and the Gatun formation are marine deposits and are richly fossiliferous; and the Bohio conglomerate and the Cucaracha, Caimito, and Gatun formations contain fossil plants. I have summarized the biological characteristics (Vaughan, 1919, **5**). Marine Eocene deposits crop out near Tonosí, Los Santos Province, and probably at David, where the limestone contains specimens of Orthophragmina. Fossils have been described as follows: Calcareous algae by M. A. Howe (1918, **1**); higher plants by E. W. Berry (1918, **1**, **2**); foraminifera by J. A. Cushman (1918, **1**, **2**); corals by T. W. Vaughan (1919, **4**); echinoids by R. T. Jackson (1917, **1**; 1918, **2**); mollusks by F. Toula (1909, **1**; 1911, **3**), A. P. Brown and H. A. Pilsbry (1911, **1**; 1913, **2** and **3**); decapod Crustacea by M. J. Rathbun (1918, **1**); Cirripedia by H. A. Pilsbry (1918, **3**).

The fossil Mollusca collected by Dr. D. F. MacDonald and myself have not been adequately studied and collections made in Panama and Costa Rica subsequent to our work in the canal zone are still awaiting examination. The results obtained in Panama are of great scientific value, but when the additional collections have been studied and the results made available in

[12] This is Oligocene.—T. W. V.

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print a still greater advance will be made in standardizing a geological section in Panama and Costa Rica.

DOMINICAN REPUBLIC

The geological section in the Dominican Republic is described by Cooke (1921, **5**) and the biological characters of the different subdivisions are presented by Vaughan and Woodring (1921), utilizing identifications of the organisms as follows: fossil plants by Berry (1921, **4**), foraminifera by Cushman; corals by T. W. Vaughan; echinoids by R. T. Jackson (1921, **3**); mollusks by C. J. Maury (1917, **2**) and W. P. Woodring; Bryozoa by Canu and Bassler (1919, **2**); and decapod Crustacea by M. J. Rathbun (1919, **2**; 1920, **3**). The geological succession shown on correlation Table 3 appears to be correct without any possibility of error. The section for the time being must, therefore, be accepted as the standard section of the West Indian Tertiary formations, and when it is later combined with the investigations of Woodring, J. S. Brown, and W. S. Burbank, West Indian stratigraphy will be in fairly good condition. But provisions need to be made for the complete description of the different faunas and the publication of the results. The faunas are very rich. There are in the Miocene deposits, the richest in number of species, about 1000 species of Mollusca.

TYPE LOCALITIES OF SUBDIVISIONS OF THE TERTIARY SYSTEM IN THE WEST INDIES AND CENTRAL AMERICA

It has already been stated that the best faunal development of a particular horizon may not be in the area of a type section where the successive divisions are seen in their stratigraphic relations. Because of the large faunas the following localities have been selected as types of horizons or stages as the term stage is used by Europeans: Upper Eocene, St. Bartholomew limestone of the Island of St. Bartholomew; middle Oligocene, Antigua formation of the Island of Antigua; upper Oligocene, Anguilla formation of the Island of Anguilla, and the upper part of the Culebra formation and the Emperador limestone of the Panama Canal zone; lower and middle Miocene, the Yaque group on the south side of the valley of Rio Yaque del Norte, Dominican Republic, with supplements from the Gatun formation of the Panama Canal zone and the

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AMA AND TA RICA	
ro lime- stone anama), Limon ta Rica)	
Gatun formation includes two or more horizons	
perador iestone ulebra mation er part)	
ılebra mation er part) stone at onosi	
Bohio omerate[6]	
iestone *Ortho- mina* on Chagres it David nama[7]	S
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Bowden marl of Jamaica; upper Miocene, Cerros de Sal formation, Dominican Republic; Pliocene, Limón, Costa Rica.

The status of knowledge of the descriptive paleontology of the different horizons in the West Indies except Porto Rico is indicated in the following table, Table 4:

TABLE NO. 4. WEST INDIAN PALEONTOLOGIC REPORTS

Group of Organisms and Author of Report	Geologic Horizon and Localities			
	Upper Eocene (St. Bartholomew)	Middle Oligocene (Antigua)	Upper Oligocene (Anguilla)	Miocene (Cuba, Jamaica, Dominican Republic)
Calcareous algae, by M. A. Howe (1919, 2)	a	a	a	o
Foraminifera, by J. A. Cushman (1919, 3)	a	a	a	a
Corals, by T. W. Vaughan (1919, 4)	b	b	b	b
Echinoids, by R. T. Jackson (1921, 3)	a	a	a	a
Bryozoa, by F. Canu and R. S. Bassler (1919, 2)	o	a	a	a
Mollusca, by C. W. Cooke (1919, 2) and W. P. Woodring (no date, 2)	a	a	a	a
Decapod Crustacea, by Mary J. Rathbun (1919, 2; 1920, 3)	a	o	a	a

a, Reports completed; b, report in preparation, preliminary summary of faunas published; o, not represented in available West Indian collections. Pliocene is not included in the table, as it seems to be known only on the south coast of Cuba.

For Porto Rico see bibliography, Hubbard (1920, 2), Jackson (1921, 3), Maury (1920, 5), Vaughan (1919, 4).

In order to indicate how a small group of organisms, the echinoids, work out when studied with reference to geological horizons a table from one of my papers (1921, 7) is republished. With reference to some of the species from the Anguillan horizon reported also to occur in the Antiguan, the records are taken from Lambert, who reported on J. W. Gregory's collection of West Indian fossil echinoids. Gregory may have found in Antigua a horizon above the one at which I collected echninoids, or there might be an error in the name of the locality. The names Anguilla and Antigua are easily confused.

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TABLE 5. WEST INDIAN ECHINOIDS OF STRATIGRAPHIC VALUE

Species	Cretaceous	Eocene	Oligocene		Miocene
			Middle	Upper	
Codiopsis arnaudi Cotteau	×				
Salenia scutigera (Münster)	×				
Phymosoma cubense (Egozcue)	×				
Conulus antillensis (Cotteau)	×				
Lanieria lanieri (Cotteau)	×				
Discoidea decorata Desor	×				
Cardiaster cubensis Jackson	×				
Hemiaster berkeyi Jackson	×				
Cidaris loveni Cotteau		×			
Sismondia antillarum Cotteau		×			
Peronella mirabilis Jackson		×			
Parapygus antillarum (Cotteau)		×			
Echinolampas antillarum Cotteau		×			
ovum-serpentis Guppy		×			
clevei Cotteau		×			
Asterostoma cubense Cotteau		×			
Pseudasterostoma jimenoi (Cotteau)		×			
Agassizia inflata Jackson		×			
Prenaster loveni Cotteau		×			
Paraster antillarum (Cotteau)		×			
subcylindricus (Cotteau)		×			
Periaster elongatus Cotteau		×			
Plagiobrissus loveni Cotteau		×			
Macropneustes antillarum (Cotteau)		×			
Eupatagus grandiflorus (Cotteau)		×			
clevei (Cotteau)		×			
antillarum (Cotteau)		×			
cubensis (Cotteau)		×			
Cidaris peloria Jackson			×		
Sismondia anguillæ Cotteau			×	×	
Clypeaster concavus Cotteau			×	×	?
lanceolatus Cotteau			×	×	
antillarum Cotteau			×	×	
planipetalus Cotteau			×		
cryptopetalus Jackson			×		
cotteaui Egozcue			×	?	
batheri Lambert			×		
parvus Michelin			×	?	
oxybaphon Jackson			×		
Echinarachnius sebastiani Jackson			×		
Echinolampas lycopersicus Guppy			×	×	
anguillæ Cotteau			×	×	
Paraster clevei (Cotteau)			×	×	
Eupatagus vaughani Jackson			×		
elegans Jackson			×		
Cidaris anguillæ Cotteau				×	
clevei Cotteau				×	

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TABLE 5. WEST INDIAN ECHINOIDS OF STRATIGRAPHIC VALUE.—Continued

Species	Cretaceous	Eocene	Oligocene		Miocene
			Middle	Upper	
melitensis				×	×
Echinometra prisca Cotteau				×	?
Echinoneus cyclostomus Leske				×	?
Echinolampas semiorbis Guppy				×	
Agassizia clevei Cotteau				×	
Paraster parkinsoni Defrance				×	
loveni (Cotteau)				×	
Macropneustes clevei (Cotteau)				×	
Brissopsis antillarum Cotteau				×	
Brissus exiguus Cotteau				×	
Cidaris tribuloides (Lamarck)					×
Echinopedina cubensis Cotteau					×
Clypeaster caudatus Jackson					×

Eupatagus abruptus (Gregory) from the Bissex Hill formation of Barbados is an Oligocene species, but whether it comes from the Antiguan or Anguillan horizon is not known.

Leaving out the echinoids for which a table has been given, the different horizons will be stated, the geographic distribution summarized, and the reasons for the correlations indicated.

EOCENE

Except in Trinidad (Maury, 1912, 1), which is really South American in its affinities, no lower Eocene is known in Central America or the West Indies, and at present middle (Lutetian) Eocene is known only in Panama near Tonosí where a varietal form of *Venericardia planicosta* occurs. Upper Eocene deposits, however, are widely distributed and where contacts may be seen with older formations they rest on folded and eroded Upper Cretaceous strata. Because of the abundance of fossil organisms there the type formation of the West Indian upper Eocene is the St. Bartholomew limestone of the Island of St. Bartholomew. Deposits of similar age are well represented in Cuba, Jamaica, the Republic of Haiti, the Dominican Republic, Trinidad, probably in Panama and Costa Rica, and in Nicaragua. They may be represented in Antigua (Hussakoff, 1907). A part of the Scotland "Series" of Barbados may also be of equivalent age. The biological characteristics of the upper Eocene are primarily taken from the St. Bartholomew limestone, but supplements are made from the Cambridge formation of Jamaica,

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the Brito formation of Nicaragua, from Cuba, and from the Ocala limestone of Florida. The horizon is characterized by three different groups of Orthophragmina. One of the groups is stellate and some of the species are large, as much as 12 mm. in diameter, *O. antillea* Cushman; other species are small, *O. subtaramellei* Cushman. The species of the second group are discoidal. Those of the third group are lenticular, that is circular in plan but thickened in the central part. Associated with Orthophragmina is Lepidocyclina and in places Carpenteria, Conulites, and large species of Operculina are abundant. The corals include a number of genera that range into higher formations but three genera, Antilloseris, Physoseris, and Dendracis, have not been found in younger deposits. All the species of corals known from the upper Eocene seem confined to that horizon (Vaughan, 1919, **4**, pp. 193-195). The mollusks include a neritinoid species of *Velates schmiedianus* aspect; and there are two brachiopods, *Argyrotheca dalli* Cooke and *Liothyrina vaughani* Cooke.

The biological affinities of the West Indian and Central American Eocene to the upper Eocene Ocala limestone, the uppermost Eocene formation of the southeastern Coastal Plain of the United States, is obvious, and close relationship with the Priabona formation of northern Italy is also clear. Therefore the St. Bartholomew limestone and its stratigraphic equivalents are confidently correlated with the Ludian of France and the Priabonian of Italy.

OLIGOCENE

No lower Oligocene strata have yet been positively identified in the West Indies or Central America, but it is indicated in Table 3 that the lower part of Tabera formation of the Dominican Republic may be of lower Oligocene age because that formation is thick and its upper part is clearly of middle Oligocene age, and certain deposits of Panama and Costa Rica may be of lower Oligocene age (Vaughan, 1919, **5**, pp. 578-580). From information at present available it appears that in some parts of the West Indies, especially Cuba, there was some orogenic movement, although this was not a period of great orogeny. Oligocene deposits are extensively developed in Jamaica but the horizons represented are not definitely known (Vaughan, 1919, **5**, pp. 580-581, 585).

Middle Oligocene.—Middle Oligocene deposits are greatly developed in the West Indies, Central America, eastern Mexico,

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and the southeastern United States. Because of its abundant fauna the Antigua formation, island of Antigua, is taken as the type formation for this horizon. It is particularly characterized by great luxuriance of species of Lepidocyclina. Cushman has described five species from Antigua, namely, *L. gigas, L. undulata, L. undosa, L. favosa,* and *L. parvula*. *L. undulata,* which attains a diameter of 100 mm., appears to be the largest known species in the genus, exceeding *L. elephantina* in size. It should be noted in passing that *Lepidocyclina mantelli* (Morton) Gümbel is not known from Antigua. It occurs at a lower horizon, the Marianna limestone of the Vicksburgian Oligocene (Cushman, 1920, **4**, pp. 57-60). A species of Heterostegina *(H. antillea)* also seems to be characteristic of the Antiguan Oligocene. Corals are numerous, there being about 69 species in the Antigua formation in Antigua. Among the most important genera are Stylocoenia, Astrocoenia, Favites, and Diploastrea. Other genera prominent in the fauna are Antiguastrea and Cyathomorphia, and many species that are confined to the Antiguan horizon belong to genera that occur at stratigraphically higher and lower horizons. The molluscan fauna is at present known to comprise only 23 species, of which 6 appear to occur at the higher Aguillan horizon. As none of the molluscan genera are confined to the Antigua formation, its discrimination from other horizons depends on differences in the species. The genera represented are Orthaulax, Turritella, Ampullinopsis, Turbo, Scapharca, Ostrea, Pecten (9 species), Amusium, Spondylus, Lithophaga, Antigona, and Chione. One interesting feature of the molluscan fauna of the horizon is that it seems to mark the introduction of the genus Orthaulax in the American Tertiary formations.

Deposits of the same, or nearly the same age, occur as follows: There is in the island of St. Croix a considerable coral fauna that is entirely identical with that of Antigua. In Porto Rico it appears that deposits equivalent or nearly equivalent in age to the Antigua formation have received six names, San Sebastian, Lares, Collazo, Juana Diaz shale, and Guanica shaly limestone. These five formations are what I had previously included under the Pepino formation of Hill, but Hill may not have intended the Pepino formation to be so limited stratigraphically (Vaughan, 1921, **7**). Deposits of Antiguan age are well developed as the upper part of the Tabera formation of the

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Dominican Republic; on the south side of Cuba east of the mouth of Guantánamo Bay, and perhaps at other places in Cuba; in the basal part of the Chattahoochee formation in southern Georgia; in eastern Mexico where they form parts of the Meson and San Rafael formations of Dumble; at several places in Panama, where they form the basal part of the Culebra formation; and Cerro Colorado, Island of Arube. According to Douvillé (1915, 2) beds of similar age occur in the island of Trinidad, but there is uncertainty regarding the stratigraphic relations of the material from Trinidad; in fact, it is not certain that it was actually in situ.

In regard to the correlation of the Antiguan horizon, it can be matched very closely with the base of the Chatahoochee formation of Georgia and Florida, which places the horizon with reference to the Coastal Plain section. The coral fauna in the Antigua formation as a whole bears close resemblance to the coral fauna of the Rupelian Oligocene of northern Italy (Vaughan, 1919, 4, pp. 199-203). Some of the genera, such as Cyathomorpha, that give the Italian fauna of Rupelian age its characteristic facies also give to the Antiguan deposits their characteristic facies. One of the commonest genera in the Antiguan deposits is Antiguastrea and the Antiguan species, *A. cellulosa* (Duncan) Vaughan (1919, 4, p. 402) is scarcely separable from *Antiguastrea elegans* (Reuss) Vaughan (1919, 4, p. 409) from the north Italian Rupelian Oligocene. There seems no reasonable doubt as to the correctness of this correlation.

Upper Oligocene.—The horizons here referred to the upper Oligocene are considered by all of those who have studied them as the correlative of the European Aquitanian, a correlation first made by Douvillé in 1898 (1898, 1). In order to get an adequate biological characterization of this horizon formations at two separate localities need to be considered. They are the island of Anguilla, the type locality of the Aguilla formation, and the Panama Canal zone, the type locality for the Culebra formation and the Emperador limestone. The upper part, not the basal part, of the Culebra formation is considered of upper Oligocene age. The foraminifera characteristic of this horizon are smallish species of Lepidocyclina, particularly of the *L. canellei* type. Two other species of Lepidocyclina are *L. chaperi* Lem. and R. Rouville, which occur stratigraphically above *L. canellei*, and *L. vaughani* Cushman. A genus to which Cushman

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has applied the name Heterosteginoides, is represented in the canal zone by *H. panamanensis* Cushman and in Anguilla by *H. antillea* Cushman. This genus has not been found at either higher or lower horizons. The genus Orbitolites becomes common at this horizon and persists to the present time. The coral faunas are rich but do not certainly contain any characteristic genera. In contrast with the older Antiguan fauna the genera Antiguastrea and Cyathomorpha have become rare and Favites, Diploastrea, and Actinacis appear to have become extinct. Orbicella and Goniopora are probably the two most important genera. There is nothing peculiar in the molluscan genera, but some of the species appear characteristic of the horizon. The Anguillan horizon is probably represented in St. Croix, and in Porto Rico by the Aguadilla limestone (Maury, 1920, **5**). It is represented by the Cevicos limestone of the Dominican Republic and it is present in Cuba at several places. It is represented by the Tampa formation of Florida, which is the equivalent of the upper part of the Chattahoochee formation; and the upper part of the San Rafael formation of eastern Mexico is probably its equivalent. The age of the Bissex Hills bed of Barbados needs mention at this place. These deposits were first described by Franks and Harrison (1898) and later R. J. L. Guppy (1911, **4**, p. 692) mentions *Echinolampus anguillae* Cotteau from the marls of Bissex Hill. The principal horizon of this echinoid is Anguillan but it is also recorded from the Antigua formation of Antigua. Assuming that Guppy has correctly identified the echinoid, its presence indicates that the Bissex Hill marl is either of upper or middle Oligocene age. The Globigerina marl of Barbados, which underlies the Bissex Hill marl, would then necessarily be of older age and would belong somewhere in the Oligocene, probably middle Oligocene.

As the basis of the correlation of this horizon with European Aquitanian was indicated in the opening sentence of the discussion of it, further remarks on that subject appear unnecessary.

MIOCENE

The greatest number of subdivisions of the Miocene made at any place in the West Indies up to the present time are those in the Dominican Republic, where six subdivisions are recognized. It will not be practicable in this brief summary to characterize each one of these horizons. For a discussion of their

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features reference may be made to the paper by Vaughan and Woodring (1921). With regard to the foraminifera found in the Miocene, the first feature that strikes one is the absence of orbitoidal genera, there are no Lepidocyclina; but Orbitolites is abundant and there are myriads of Amphistegina and Asterigina. The corals include many specimens and numerous species of Placocyathus, Asterosmilia, Antillea, Thysanus, Teleiophyllia, and Syzygophyllia. Among the genera that occur in both the Oligocene and Miocene are Stylophora, Pocillopora, and Goniopora. One of the characteristics of the Miocene coral fauna is that it includes not only representatives of the genera of the present Caribbean fauna but many of the Miocene species are distinguishable either with difficulty or not at all from species at present living in the Caribbean region. This statement applies to species of Dichocoenia, Meandrina, Stephanocoenia, Orbicella, Maeandra, Agaricia, Siderastrea, and Porites. The molluscan faunas are enormously rich and probably aggregate 1500 or more species. The bryozoan faunas are rich and a considerable number of crustacean species have been described.

Deposits of Miocene age are known from Porto Rico, Cuba, Jamaica, eastern Mexico, the Isthmus of Tehuantepec, Nicaragua, Costa Rica, Panama, northern Colombia, Trinidad, and the Island of Martinique. Very low Miocene may be present on the Island of St. Croix.

With regard to the correlation of the West Indian Miocene faunas, the Baitoa formation of the Dominican Republic on the basis of the corals and mollusks appears to be the correlative of the Chipola marl which is the basal member of the Alum Bluff formation of Florida. The Chipola marl is correlated with the lower Burdigalian of Europe partly on the evidence of the bryozoa. A somewhat higher horizon than the Chipola marl in the Alum Bluff formation is correlated on the basis of fossil vertebrates, particularly Merychippus, with the Burdigalian (Vaughan, 1919, 4, pp. 219-229).[13] The sum total of the evidence seems to be decisively in favor of correlating the Alum Bluff formation and its West Indian equivalents with the Burdigalian of Europe. The next higher Miocene horizon, which is represented by the Gurabo formation of the Dominican Republic, the Bowden marl of Jamaica, and the upper part of the Gatun

[13] Correlation by E. H. Sellards and J. C. Merriam quoted by Vaughan.

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formation of the Canal Zone, is probably the equivalent of the European Helvetian. The highest subdivision of the Miocene of the Dominican Republic, the Cerros de Sal formation, is tentatively considered the equivalent of the European Tortonian or perhaps one of the higher horizons.

PLIOCENE

Marine Pliocene is only slightly developed in the West Indies and Central America. The principal areas of outcrop are in the Yucatan Peninsula and at Limón, Costa Rica. Apparently there is a very small development of Pliocene on the south coast of Cuba east of the mouth of Guantánamo Bay, but too little is known of these Pliocene deposits to warrant extended discussion of them. I have summarized what is known regarding the corals in my paper (1919, 4, p. 223).

CONCLUSION

In the foregoing review an effort has been made to convey some idea of the amount of research that has been done on the stratigraphic relations, biological characteristics, and the geological correlation of the Tertiary formations of Central America and the West Indies. It is obvious that a great deal has been done and that it is probable that the major groups have been recognized and correlated with a considerable degree of precision with the recognized European standard sections, but it should also be made clear that notwithstanding progress an enormous amount of work remains to be done. By consulting the paper on the status of areal geological mapping in Central America and the West Indies any one will see what large deficiencies there are in knowledge of the areal geology of the Caribbean region. Deficiencies in knowledge of areal geology usually mean deficiencies in knowledge of stratigraphy. Besides the deficiencies that have been indicated it will be pointed out that the work on many of the groups of organisms is entirely inadequate. All of the papers on the calcareous algae are listed in the accompanying bibliography. They are all by Howe. The paper by Martin cited in the bibliography contains a description of *Lithothamnium curasavicum* from the Cretaceous of the Island Curacao. The only papers on the foraminifera that possess any particular worth are those by Cushman and Douvillè. Of these those by Cushman are of by far the greater value

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because they are related to actual studies in stratigraphy. Scarcely more than fifty per cent of the corals known from the West Indies have yet been described. For years I have been engaged on studies of this group of organisms but interruption because of other duties has prevented my finishing the work. The fossii echinoids, thanks to Robert T. Jackson, are fairly well known and the different species are with relatively few exceptions definitely tied into the stratigraphic column. The mollusks have been only partly described, but much progress has been made by Dall, Guppy, Toula, Böse, Pilsbry, Brown and Pilsbry, Pilsbry and Johnson, Cossmann, Maury, Cooke, and Woodring. However, enormous collections from the Isthmus of Tehuantepec, Costa Rica, Panama, Colombia, Trinidad, and the Dominican and Haitian Republics are still awaiting critical study. Only a few species of brachiopods are known from the Caribbean region, and these have been described by Guppy and Cooke. Knowledge of the fossil bryozoa will probably be in satisfactory condition when the second part of the work on American Tertiary bryozoa by Canu and Bassler has been published. All available collections of fossil crustacea have been described by Rathbun. Reference to the bibliography will show that the only Tertiary vertebrates, except shark teeth, that have been described are a surgeon fish from Antigua by Hussakoff, a sirenian from Porto Rico by W. D. Matthew, and a sirenian by Martin from Serro Colorado, Arube.[14] Considerable work has been done in recent years on the Pleistocene veterbrates of the West Indies by Matthew, Anthony, Miller, and others, and their researches have brought to light many facts of value in understanding the geological history of the West Indian region, but their work is considered outside the scope of the present paper. One of the particular needs in further work on West Indian stratigraphy and paleontology is to try to get more information on fossil vertebrates, particularly on pelagic mammals.

A more adequate understanding of the geological history of both the North American and South American continents and of other areas that lie either on the margin of or within the Pacific basin, is largely dependent upon more complete knowledge of the stratigraphy, paleontology, and geological history of the Caribbean region, and it is hoped that researches in

[14] The corals from this locality are of Oligocene age (Vaughan, 1919, 4, p. 207).

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this region can be prosecuted with vigor so as to meet the needs for progress in related fields of geology.

In order to indicate more clearly the bearing of the data presented in the foregoing discussion on problems of general geological history, this paper is closed by a tabular summary of some important events in the geological history of the West Indies and Central America, revised from tables I have previously published (1919, **3**, 1919, **5**) so as to include more recent information (Vaughan, 1920, **6**), Cooke, (1921, **5**), and (Vaughan and Woodring, 1921). Three periods of major diastrophism in the Greater Antilles are known as follows: (1) late Paleozoic; (2) early Tertiary; (3) late Tertiary.

TABULAR SUMMARY OF SOME IMPORTANT EVENTS IN THE GEOLOGICAL HISTORY OF THE WEST INDIES AND CENTRAL AMERICA

Epoch		Events
Recent		Submergence of land areas, probably resulting from deglaciation, except local differential crustal movements, in places producing uplift.
Pleistocene		Emergence of large areas, probably due to withdrawal of water to form the continental ice-sheets; also oscillation of land areas by differential crustal movement.
Pliocene		Local moderate submergence, *period of cataclysmic faulting* breaking up a large land area and forming the Antilles nearly as they are at present. Probably a narrow interoceanic connection that admitted an Atlantic fauna into the present site of the Gulf of California.
Miocene	Upper	Extensive emergence of the land joining North and South America through Central America; Greater Antilles joined to each other, and possibly to Central America, by bridges from Jamaica to Honduras and from western Cuba to Yucatan, and to South America along the Caribbean arc. All these supposed connections not necessarily contemporaneous. Local submergence in places.
	Middle	Extensive marginal submergence in some of the West Indies and on the Atlantic side of Central America. No known interoceanic connections.
	Lower	Extensive submergence in the West Indies and around the continental margins; narrow, areally limited interoceanic connections; land emerging in Central America.

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Epoch	Events
Oligocene	Upper.......Extensive submergence with interoceanic connections. Middle.....Maximum areal submergence with extensive interoceanic connections. Lower......Probably extensive submergence in Central America and certainly in the southeastern United States; mostly emergence in the West Indies. Minor diastrophism in the Greater Antilles.
Eocene	Upper........Extensive submergence with interoceanic connections. Middle......Apparently interoceanic connection across Central America. Lower........Emergence of the Greater Antilles and probably in Central America. No known interoceanic connection. Period of major diastrophism in the West Indies
Cretaceous[3]	Upper........Extensive submergence, but without interoceanic connection. Lower........Submergence in southern Mexico and Central America, especially in late Comanche time. Probable emergence in the Greater Antilles. No interoceanic connection.
Jurassic	Upper........Submergence in western Cuba, eastern Mexico, and west Texas, without interoceanic connection, except possibly in late Upper Jurassic time. Middle......Submergence in southern Mexico (Oaxaca and Guerrero), with possible interoceanic connection. Lower........Submergence in southeastern Mexico (Puebla, Vera Cruz, and Hidalgo, possibly also in Guerrero), with possible interoceanic connection. Non-marine plant-bearing beds in same region and and also in Oaxaca. Possibly the latter may be the same age as the supposed Rhætic plant-bearing beds of Honduras and Nicaragua.
Triassic	Upper (Rhætic)........Plant-bearing beds in Honduras and Nicaragua, above mentioned, bespeak land conditions in latest Triassic or earliest Jurassic. Upper (Karnic)........Submergence in central Mexico (Zacatecas), with probable interoceanic connection. Middle......Probable land conditions throughout Mexico and Central America. Lower........Probable land conditions throughout Mexico and Central America.
Late Paleozoic	Formation of the major tectonic axes of Central America and the initial east and west axes of the Greater Antilles.

[3] Mesozoic history of Central America, Mexico, and the West Indies, by T. W. Stanton.

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TERTIARY FORMATIONS OF WESTERN SOUTH AMERICA

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(Presented at the request of the Committee on Program)

INTRODUCTION

In attempting a summary of the Tertiary of the West Coast of South America at this time the reader should be cautioned that many of the conclusions must be regarded as tentative because of the immense size of the area and the lack of any information regarding most of it. That information on many doubtful points will be forthcoming in the near future is probable.

The following investigations known to the writer are wholly or partially completed but the material is not yet available for publication. Dr. T. O. Bosworth and Prof. Henry Woods have in manuscript an account of the geology and paleontology of northwestern Peru, of which only a very brief abstract has been published:[1] Dr. E. M. Spieker, in a dissertation submitted to the Johns Hopkins University, has given an account of the paleontology of the Zorritos formation of Peru which includes a restudy of the Nelson collection:[2] Messrs. Van Holst and Singewald have made detailed field studies in the Zorritos region, the results of which are subject to certain delays because of commercial reasons: the writer has in manuscript an account of the Tertiary around Concepcion, Chile: Dr. Singewald and the writer have completed an account of the geology and paleontology around Corocoro, Bolivia, and the Bureau of Mines of Peru has collected much material and contemplates a second report on the North Peruvian oil fields; and there are at the Hopkins considerable Tertiary collections from Ecuador not yet studied. The writer has had the benefit of much of this unpublished work as well as the privilege of personally visiting many of the localities in South America and examining the extensive paleontological collections under the charge of Director Bravo at Lima.

[1] Proc. Geol. Soc. Lond. No. 1062, pp. 20-21, 1920.

[2] Nelson, E. T. On the Molluscan fauna of the late Tertiary of Peru. Trans. Conn. Acad. vol. 2, pt. 1, 1870.

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The area covered in the present abstract comprises the Andes and West Coast, but no attempt will be made to include the late Tertiary east of the front range although there is some information from scattered localities in eastern Peru, eastern Bolivia and western Argentina, and in particular the extensive Tertiary deposits of the latter country with their wealth of mammalian remains will for the most part be entirely ignored, since they have received detailed and authoritative treatment in recent years by both vertebrate and invertebrate experts.

COLOMBIA

One would expect to find much the same Tertiary sequence as that of the Panama Canal zone in some part of western Columbia but practically nothing is known of the region west of the western Andes between Latitude 8° N. and 10° South. Pilsbry and Brown[3] reported a Gatun fauna from near Cartagena in northern Colombia and Vaughan[4] records a similar assemblage from various localities in the northern interior. Karsten[5] mentioned marine Tertiary of unknown age much farther south in the vicinity of Popayan, between the Eastern and Western Andes in the Upper Cauca valley, and also listed numerous localities where mammalian bones had been observed. Vaughan[6] reports Eocene from one league west of Arroyo Hondo, Bolivar, Colombia, on the basis of the determination of Nummulites and Stellate Orthophragmina by Cushman.

Tertiary fossil plants have been described from two localities. A small collection was obtained near Buga in the Upper Cauca valley from an undeterminable Miocene horizon and a large collection was described by Engelhardt[7] from near Santa Ana (970 meters) in the Rio Magdalena valley, State of Honda. Both occur in tuffs and as the last locality is in the Cordillera de Bogotá which swings to the eastward to form the Cordillera de Merida of Venezuela, recent plant collections from the latter[8] throw some light on the age of the former.

[3] Pilsbry, H A. and Brown, A. P., Phila. Acad. Nat. Sci., Proc. for 1917, pp. 32-41.

[4] Vaughan, T. W., U. S. Natl. Mus., Bull. 103, pp. 588-589, 1919.

[5] Karsten, H., Géologie de Vénézuela, Nouvelle-Grenade et Equador, Berlin, 1886.

[6] Op. cit., p. 197.

[7] Engelhardt, H., Abh. Senck. Naturf. Gesell., Bd. 19, 1895.

[8] Berry, E. W., U. S. Natl. Mus., Proc. (In press.)

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The Santa Ana flora comprises the following:

Bambusium Stubeli
Rhizoma graminis
Helicoma elegans
Stenospermatium columbiense
Ficus laqueata
Persea coriacea
    macrophylloides
    elliptica
    elongata
Nectandra curvatidolia
    Reissi
    areolata
Goeppertia subherbacea
Acrodiclidium chartaceum
Laurophyllum rigidum
Bothriospora Witti
Citharexylon retiforme
Tecoma grandidentata
Chrysophyllum rufoides
Styrax lanceolata
Buettneria cinnamomifolia
Moschoxylon tenuinerve
Ilex arcinervis
Gouiana membranacea
    firma
Condaminea grandifolia
Vochysia retusifolia
Trigonia varians
Moquillea Stubeli
Inga Reissi
Pithecolobium tenuifolium
Phyllites abutoides
    strychnoides
    vochysioides

These are well distributed among the natural orders and indicate a characteristic mesophytic tropical flora with conspicuous South American elements such as Stenospermatium, Goeppertia, Acrodiclidium, Condominea, Vochysia, Trigonia, Heliconia, etc. Two of the species are common to the Costa Rica Miocene, two are common to the Navidad beds of Chile and one is found in the Loja basin of Ecuador. The writer was formerly inclined to regard this flora as lower Miocene but in the light of the more recently studied collections from Costa Rica and Venezuela it must be regarded as middle or upper Miocene.

ECUADOR

Marine Tertiary deposits of shallow water origin are known to be extensively developed for several hundred miles along the

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Ecuadorian coast.[9] Detailed field studies by Cunningham Craig and Wallis made for petroleum interests are not yet available for publication but suggest a threefold division of the deposits. From a superficial examination of collections the writer would consider that the Zorritos, Talara and Paita stages of northern Peru continue along the Ecuadorian coast, where their relations are obscured by the same extensive block faulting and intermixture of forms from Pleistocene shell marls that have made the unravelling of the north Peruvian coastal region so difficult. Whether the older Tertiary of the latter region is present in Ecuador cannot be stated.

Continental deposits of Tertiary age are doubtless present in many of the valleys and continental basins of the Ecuadorian Andes. Fossil plants are known from several localities including Tablayacu in the Rio Jubones basin and a number of points in the Loja basin where they are associated with lignites of some commercial value.[10] This flora which consists of over 40 species,[11] is distinctly South American in facies, denotes a mesophytic tropical environment and from its points of contact with other fossil floras in western South America is certainly of Miocene age and very probably lower Miocene.

Sphaerites punctiformis
sparsus
consociatus
Xylomites immersus
Hysterites ellipticus
Scleria Wolfi
Arthante geniculatoides
Hieronymia Lehmanni
Camphoromoea speciosa
Endlichera rhamnoides
Phoradendron fossile
Myriastica fossilis
Bombax retusifolium
Luhea tertiaria
Hiraea cyclosperma
Banisteria aceroides
Tapiria lanceolata
Vochysia Witti
ferruginoides
Eugenia ovalifolia

[9] Wolf, T. Geografiá y Geologia del Ecuador, Leipzig, 1892.

[10] Wolf, T., and Rath, G., Zeits. Deutsch. Geol. Gesell. Bd. 28, pp. 391-303. 1876;
Engelhardt, H., Abh. Senck. Naturf. Gesell. Bd. 19, 1895;
Berry, E. W., Bull. Geol. Soc. Am., vol. 29, p. 640, 1918.

[11] Engelhardt, H., Abh. Senck. Naturf. Gesell. Bd. 19, 1895.

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Myrcia antediluviana
Myrciaria tenuidolia
Lonchocarpus obtisifolius
Stenolobium rhomboidalis
Caesalpinia subdimidiata
Cassia dimidiato-linearis
    linearifolia
    longifolia
Macrolobium tenuifolium
Pterogyne oblongifolia
Inga ovalifolia
    latifolia
Phyllites colubrinoides
    styracioides
    celastrinoides
    gouareoides
Leguminosites grandis
    machaerioides
    cassioides
    acaciaeformis

Considerable has been written regarding the mammalian remains of upland Ecuador. These in common with similar remains found all along the Andean region have been variously regarded as either Pliocene or Pleistocene, a question difficult of solution since there was no continental ice sheet present and, so far as the writer's observations go, all of the fossiliferous records antedate the maximum development of mountain glaciers whose shrunken remnants still clothe the higher mountain masses.

Mammalian remains embedded in cave deposits, river terraces and lacustrine tuffs are not uncommon throughout the whole Andean region and are probably much more abundant than the rather meager records indicate. These are frequently considered to be of Pleistocene age but many are undoubtedly Pliocene.[12] From Imbabura, Malchingui (2878 meters), Cotocallao (2802 meters) and Alangasi (2887 meters) near Quito and near Rio Bamba (3342 meters) and Punin (2778 meters) southeast of Chimborazo, also along Rio Paromos and Rio Sisgun in Ecuador have been recorded Mylodon, Equus, Protauchenia, Cervus, Mastodon, Machaerodus, Callistrophus, etc.

PERU

Aside from the description of a few species of Tertiary marine fossils by d'Orbigny,[13] Nelson,[14] and Gabb,[15] the general

[12] Wolf, T., Geognostische Mittheilungen aus Ecuador: Neues Jahrb. p. 155, 1875.

[13] d'Orbigny, A., Paléontologie du Voyage l'Amerique méridionale: Paris, 1842.

[14] Nelson, E. T., Trans. Conn. Acad., vol. 2, pt. 1, 1870.

[15] Gabb, W. M., Jour. Acad. Nat. Sci. Phila. ser. 2, vol. 8, 1877.

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work of Raimondi,[16] and incidental references in Darwin's Voyage of the Beagle[17] the first detailed account of the geology of any locality in northern Peru is that of Grzybowski[18] based upon a short reconnaissance in the vicinity of Tumbez and Paita in 1898. This work, although obviously superficial and uncritical, may be taken as a basis of discussion. Grzybowski segregates the Tertiary in the following units with a total thickness of about 2100 feet and the assigned ages as given below:

Paita stage	= Pliocene
Talara stage	= Upper Miocene
Zorritos stage	= Miocene
Heath stage	= Lower Miocene
Ovibio stage	= Oligocene

Grzybowski's Ovibio stage was based on flysch-like sandstones seen only inland from the coast along the northeastern flanks of the Cordillera de Amotape and said to have yielded *Turritella tricarinata* Broc. and *Solen microsulcatus* Grz., the former an European Upper Miocene species. Grzybowski considered the Ovibio stage as of Upper Oligocene age, although there is no satisfactory evidence on this point, or on the relations of the Ovibio to the balance of the Tertiary.

Marsters, in 1907, published an extended account of the north Peruvian oil fields,[19] in which there are many detailed observations and local sections and in which the exposures around Lobitos and Negritos were described.

In 1908 Adams proposed the following formational names for coastal Peru[20] with the assigned ages given below:

Barranco formation	> Rimac and other delta deposits	Pleistocene
Pacasmayo formation	> coastal terraces at Eten, Pacasmayo, etc.	Pleistocene
Pisco formation	> coastal plain at Pisco Plio-Pleistocene	
Moquegua formation	= Pliocene	
Amotape formation	= Miocene	

[16] Raimondi, A., El Perú, vol. 4, Lima, 1902.

[17] Admirable discussions of the broader aspects of the physiographic history of the Peruvian region are given by Bowman, I., The Andes of Southern Peru: Am. Geogr. Soc., 1916.

[18] Grzybowski, J., Neues Jahrb. Beil. Bd. 12, pp. 610-664, pls. 15-20, 1899.

[19] Marsters, V. F., Informe preliminar sobre la Zona, Petrolífera del Norte del Perú: Cuerpo de Ingenieros de Minas, Bol. No. 50, 1907.

[20] Adams, G. I., Outline of the Geology of Peru, Smithsonian Report for 1908, 1909.

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The last corresponds approximately with Grzybowski's Heath. Zorritos and Talara stages, known to be distinct, and after seeing all of the others except the Moquegua the writer cannot see that these terms have any chronologic value or utility and that the Moquegua is composite is shown from Bowman's observations, which will be cited after describing the Tertiary of the northern coastal region.

In 1919 the present writer described a small collection of fossil plants from near Tumbez.[21] These were erroneously referred to the Heath stage of Grzybowski, as will be explained in a subsequent paragraph, and were considered to be of lower Miocene age, a determination that has been since confirmed by Spieker's study of the Zorritos molluscan fauna (MS) in which the plant horizon is interbedded.

The field studies of Bosworth, whose collections from the basis of Wood's account of the Paleontology[22] resulted in the conclusion that the Tertiary of northern Peru

> consists of 15,000 to 25,000 feet of clay-shales and sandstones, with innumerable thin seams of beach-pebbles and shells Thus, during the Tertiary Period, a large subsidence was in progress.
>
> The stratigraphical succession is as follows:

Miocene	Zorritos formation 5000+ ft.		
Eocene	Lobitos formation 5000+ ft.		
	Negritos formation	Clavilithes series	7000+ ft.
		Turritella series	

Bosworth states that these materials were subjected to intense block faulting with differential displacements of many thousand feet.

It is obviously impossible to criticize these conclusions in advance of the publication of Bosworth's complete paper. It would seem, however, that the formational names are used in a new sense, and from the detailed instrumental surveys of Van Holst and Singewald in a restricted part of the area, the writer is inclined to consider the enormous thicknesses and the implied subsidence as due to duplication of strata, and the opinion is ventured that 2500 to 3500 feet would be nearer the facts than are Bosworth's figures of from 15,000 to 25,000 feet. It is true there has been much block faulting but the displacements observed by the former geologists are all relatively small.

[21] Berry, E. W., Proc. U. S. Natl. Mus., vol. 55, No. 2270, 1919.
[22] Proc. Geol. Soc. Lond. No. 1062, pp. 20-21, 1920.

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The writer's conception of the north Peruvian marine section is as follows:

Paita stage of Grzybowski. This comprises, according to that author, about 250 feet of sandstones and conglomerates, conformable on the underlying Talara stage. The deposits are distinctly littoral in character. The fauna comprises the following 10 species, two of which are known to be recent and some of the others are close to, if not identical with, recent forms:

Pecten paytensis Grz.
  intercostatus Grz.
  densicinctus Grz.
Ostrea oculata Grz.
  lunaris Grz.
Arca reversa Gray
Glycimeris paytensis d'Orb.
Raeta gibbosa Gabb
Venus saginata Phillipi
Chione columbensis Sowerby

The Paita stage may correspond to the marginal submergence represented by the Toro limestone of Panama, and the Coquimbo and Caldera beds of Chile, but there is a suspicion that it represents mixed collections from Miocene outcrops overlain by marine terrace deposits containing recent species of Mollusca.

Talara stage. This consists of between 200 and 250 feet of gray argillaceous sandstone grading into somewhat sandy tan-colored gypsiferous shales similar in lithologic character to the sandy part of the Heath stage. It underlies the Paita stage with apparent conformity and in places is abundantly fossiliferous, the shaly portions containing mostly small pelecypods.

Grzybowski records the following forms from this horizon, their age being considered upper Miocene:

Nucula araucana Phil.
  minuscula Grz.
Lucina pulchella Grz.
Corbula lanceolata Grz.
Cardium procurvatum Grz.
Columbella buccata Grz.
  longistoma Grz.
  turrita Grz.
Fusus inflatus Grz.
Mitra labiata Grz.
Strombus furcatus Grz.
Natica elata Grz.
Sigaretus excentricus Grz.

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Zorritos stage. This is a well defined paleontologic unit representing shallow marine sediments consisting of interbedded calcareous sands, marls, and conglomerates, with a middle lagoonal phase consisting of variegated sands and gypsiferous clay lenses with lignitic and plant-bearing layers. The plants described by the writer (op. cit.) came from this middle Zorritos, which Grzybowski mistakenly referred to his Heath stage. The true Heath has not been observed to contain any variety of marine forms and the Mollusca recorded by Grzybowski from the Heath stage appear to have been collected from this middle member of the Zorritos formation. Judging by the thicknesses given, Bosworth included Grzybowski's Heath stage in what he terms the Zorritos formation.

The true Zorritos is readily distinguished from the overlying Talara and underlying Heath. It reaches a maximum thickness of 755 feet. There is much petrified wood near the top and this horizon probably represents the Arbol sandstone of the Peruvian geologists. It contains a profuse molluscan fauna in its lower and upper members and a sparse flora and fauna in its middle member. These separate faunas show a certain contrast which is believed to be an environmental and not a chronologic facies as will be brought out in Mr. Spieker's report. The Zorritos is known to continue northward into Ecuador. It extends southward from Zorritos along the coast nearly to Talara, is exposed at Talara and also outcrops in the bend of the Amotape River in the Province of Sullana. Its fauna shows but slight relationship with that of the Californian Tertiary but has much in common with that of the Caribbean Miocene and to a less extent that of southern Europe. It is closely allied to the Gatun fauna of Panama and the Chipola fauna of Florida and is of Burdigalian age although it appears to be slightly older than the fauna of the Bowden marl of Jamaica.

It appears to be of the same age as the so-called Navidad fauna of southern Chile (the Navidad is believed to represent more than a single horizon), but has scarcely anything in common with the latter. This would seem to indicate a westward continental extension somewhere between latitudes 10° and 30° South which diverted the lower Miocene Humboldt current off shore and dissipated whatever climatic influence it may have had at that time, since the differences between the Zorritos and Navidad faunas cannot be explained by mere differences in

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latitude because the Navidad beds contain a profuse warm temperate terrestrial flora of unmistakable character.

The Heath stage has a thickness of at least 1000 feet.[23] It consists of prevailingly dark shaley deposits with subordinate amounts of sand with considerable gypsum and carbonate nodules in its upper part. Aside from greenish clays with abundant remains of the Pteropod genus Clio and occasional sharks' teeth no fossils were observed in the Heath and it is of unknown age. The sediments are believed to have been deposited in deeper water than the balance of the Tertiary in this region.

The Lobitos formation comprises an unknown thickness of interbedded shales and sandstones with layers of beach shingle. It contains an extensive fauna entirely different from that of the Zorritos. In its upper part it contains Lepidocyclina and Orthophragmina. A large oyster, suggestive of *Ostrea georgiana* is conspicuous and a cursory examination of the collections from this horizon at Lima and at the Johns Hopkins University suggests that the Lobitos represents the upper Claiborne and Jackson of the United States Gulf section or in terms of the European section the Auversian, Bartonian and Ludian stages.

The Negritos formation, the oldest Tertiary in this region, comprises an unknown thickness of interbedded sandy and clayey strata with layers of conglomeratic material. It corresponds to the lower Clay of the Peruvian Bureau of Mines and contains an extensive marine fauna and some petrified wood. According to Marsters an extensive land flora is present at certain horizons but I have not seen any collections of plants from this horizon. The sediments are prevailingly very shallow water and littoral in character and the fauna is large and, according to Woods, consists of for the most part new species. Mollusca predominate although fishes, crustacea, corals and a single echinoid are represented. A large Aturia[24] is not uncommon and other genera such as Turritella, Ostrea, Pecten, etc. Woods considers (op. cit.) that the stages of evolution of the *Venericardia planicosta* group indicate a correlation with the Tejon beds of California and with the Wilcox and lower Claiborne of the Gulf Section of the United States. A cursory examination of the collections at Lima and those presented to the Johns Hopkins University through the courtesy of Señor Bravo indicate but

[23] Boring at Negritos passed through over 1100 feet of Heath.

[24] This may be *Hercoglossa Conrad* (*Enclimatoceras Hyatt*) which is the only Cephalopod in my collections from the Negritos.

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slight relationship with the Tejon and more pronounced relationship with the Claiborne. The Negritos may well represent a part of the Wilcox, but in the writer's judgment the initial marine transgression in Peru occurred well after the beginning of Eocene time. The question of the exact date of the first Eocène seaway between the Caribbean and the Pacific must await the publication of Woods' paleontological studies. From the geological history of the canal zone and the unmistakable evidence of emergence during the late Cretaceous and early Eocene from Panama south to Patagonia and Graham Land (see tabular summary in Berry, E. W., Bull. Geo. Soc. Am., vol. 29, 1918), the writer would be inclined to date the initial submergence as the correlative of that of the lower Claiborne in the Mississippi embayment.

There is no known marine Tertiary in the central coastal region except the so-called Pisco and Barranco formations of Adams. The former is said to contain whale remains and a few shells but these have never been studied. Its age is given by Adams as Plio-pleistocene and that of the Barranco as Pleistocene. In the southern coast region and extending southward at least as far as Arica are materials comprising what Adams called the Moquegua formation. These are sands and some clays with much detrital volcanic material and as far as known are unfossiliferous. In the Vitor valley they are capped with lava flows from El Misti and are said to reach a thickness of 1500 feet. Similar deposits are described in more detail by Bowman from exposures in the Majes valley. Here the materials are prevailingly sandy, frequently crossbedded and ripple marked, and contain conglomeratic lenses. Three disconformable series are differentiated, the whole upwards of 5000 feet thick—the lower sandstone, upper sandstone and largely aeolian capping, all without observable fossils. They are considered as having been formed during the Tertiary uplift of the western Andes on wide floodplains by piedmont streams and appear to show a progressive diminution of rainfall, undoubtedly to be correlated with uplift. Their age is thus Tertiary to Recent.

No Tertiary plant beds are known from the Andean region in Peru but such undoubtedly exist and in particular the numerous high basin deposits and the enormous beds of ash and tuff covering the western Andes may be expected to furnish not only the date but some measure of the amount of uplift. The small

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flora of the Zorritos shows clearly that at that time the mountains were not sufficiently elevated to modify the climate such as it was subsequently.

There are numerous records of late Tertiary mammalian remains from various localities in Peru—in terrace, basin, and cave deposits. The most varied faunule is that described by Nordenskiöld[25] from a cave known as La Casa del Diablo (3819 meters). This included

Scelidotherium Capellinii Gervais & Ameghino
Hyperhippodium peruanum (Nord.) Sefve[26]
Canis peruanus Nord.
Felis sp.
Mephitis sp.
Auchenia lama Illig.
vicugna Molina
Furcifer (?) Wingei Nord.
Dicotyles sp.
Lagidium peruanum Meyer

Several horizons are represented since the fauna is evidently mixed in age and human skeletons were found beneath some of the mammalian remains as well as above them.

Scelidotherium was also recorded by Gervais[27] from a cave near Cerro de Pasco at 4000 meters. Parahipparion, Hippidium, Mylodon and Megatherium are recorded from Tirapata, and Eaton[28] has recently recorded Myelodon, Parahipparion, Auchenia (Lama), *Dibelodon brachyceras* and *Odocoilens brachyceros* from Ayusbamba.

BOLIVIA

The Tertiary of Bolivia is, so far as known, entirely of the continental type. The rising mountains and the great volcanic activity in the western range combined to contribute an exceedingly large amount of material to a region covered with a normal forest appropriate to the latitude. Fossiliferous localities east of the divide of the eastern Andes, as at Potosi, north of Cochabamba and elsewhere in the eastern part of the country are too remote for inclusion in the present paper, although of great interest in determining the time and amount of uplift of the mountains.

[25] Nordenskiöld, E., Ein neuer fundort für Säugetierfossilien in Peru: Arkiv. für zoologi, Bd. 4, 1908.
[26] Sefve, I. Kgl. Svensk. veten: Akad. Handl. Bd. 46, No. 2, 1910.
[27] De Castelnau Expedition dans l'Amerique du Sud.
[28] Eaton, G. F., Am. Jour. Sci., vol. 37, pp. 141-154, 1914.

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Although frequently interpreted as lacustrine deposits the great bulk of the thick series skirting the main chains of the Andes and attaining enormous thicknesses on the high plateau or altaplanicie, are stream valley fill (waste slopes) and aeolian.

At Corocoro these deposits are capable of a three-fold division which Berry and Singewald, in an unpublished manscript, have called the Vetas, Ramos and Desaguadero series. The first two are of considerable economic interest because of their copper content and because they have had various earlier ages assigned to them, ranging from Carboniferous to Cretaceous. These, which were little more than guesses, need not be cited here.

The Vetas series comprise over 5000 feet[29] of interbedded red sun-cracked shales (53 per cent), red and gray sandstone (25 per cent) and gray conglomeratic sandstones and conglomerates (22 per cent). These beds are non-gypsiferous and the sands consist of quartz and feldspar (plagioclase), the latter often fresh and glassy and in excess of the former, with considerable chlorite and some calcite. Pebbles are igneous, commonly hornblende-andesite porphyry or hornblende-diorite porphyry. Fossil plants are exceedingly common, especially in association with the copper, 23 species having been determined. Of these 83 per cent are identical with the very much more extensive Pliocene flora described from Potosi. Similar plant and copper bearing beds are found to the southward as far as Chacarilla.

The Ramos series comprise a still greater thickness of mostly red, very gypsiferous shales (81 per cent) and sandstones (19 per cent) with less than 1 per cent of conglomerate. Beds are ripple marked and sun-cracked and without fossils except for *Macrauchenia boliviensis* (Huxley). Overlying the Ramos is the Desaguadero series which lacks copper mineralization and gypsum and consists essentially of red often sun-cracked shales with subordinate amounts of fine-grained sandstone. Much of the material is of volcanic origin. The age is uncertain, the only known fossil being an Edentate footprint which may be either Pliocene or Pleistocene. It is believed that the Desaguadero series is of wide extent in the inter-Andean region of Bolivia and in part at least the equivalent of the *Puna schichten* of

[29] Thicknesses were measured in the usual way, but are probably excessive because of slope deposition.

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Pompeckj[30] and the Mauri volcanic series of Douglas[31] from which last a fragment of Nesodon and silicified wood of some species of Lauraceae have been recorded, and that it corresponds to the mammal beds at Ullonia (3800 meters) from which the following have been recorded:

Mastodon bolivianus
Megatherium sundti
Scelidotherium bolivianium
Macrauchenia ullomensis
Hippidium varium
Parahipparion boliviarium

and with the plant bearing tuffs at Jancocata which contain a considerable unpublished flora representing the genera Alnus, Osteomeles, Polylepis, Cassia, Pteris, etc.

Remains of Megatherium are not uncommon at many localities on the high plateau associated with Macrauchenia and Hippidium (as on Lake Titicaca, at Miraflores, Sucre, etc.) and a considerable mammalian fauna has been described from the Tarija region (1900 meters) which includes Glyptodon, Hippidium, Lestodon, Megatherium, Mastodon, Scelidotherium, Mylodon, Macrauchenia, Canis, Auchenia, Machaerodus, Hydrochoerus, Euphractus, etc.

Nothing is known regarding the Tertiary continental deposits west of the Cordillera Occidental in Bolivia where the region is largely buried by volcanic débris of late Tertiary to Recent age.

CHILE

There are at least two marine Tertiary horizons along the western coast of Chile. The oldest of these constitutes the so-called Navidad beds. These are shallow water, prevailingly arenaceous sediments, with locally a considerable fauna. Their areal distribution, stratigraphic or structural relations have never been described in any detail and there has been a tendency, well exemplified by Moricke, to carry the name to uncertain limits. Scattered outcrops from latitude 30° to 40° South, and possibly beyond, have been recognized. The fauna, which is extensive, has been described principally by Phillipi[32] and Möricke.[33]

[30] Pompeckj, J. F., Paleontographica, Bd. 52, 1905.
[31] Douglas, J. A., Quart. Jour. Geol. Soc. Lond., vol. 70, p. 23, 1914.
[32] Phillipi, R A., Die tertiären und quartären Versteinerungen Chiles: Leipzig, 1887.
[33] Möricke, W., Neues Jahrb. Beil., Bd. 10, pp. 548-612, pl. 11-13, 1896.

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It shows no close relationships with the faunas of corresponding age around the borders of the Gulf of Mexico and Caribbean and practically no similarity to the contemporaneous fauna of the Zorritos formation of northern Peru. Its relations are with the Tertiary faunas of the southern hemisphere and especially with the nearby faunas of southern Argentina, 34 of the Navidad species occurring in the Patagonian and 4 in the Magellanian of Argentina.

The Navidad beds rest unconformably on the upper Cretaceous[34] in the Concepcion-Arauco region where best known, and comprise a basal conglomerate overlain by a series of shales and coarse sandstones with coal seams. The beds vary greatly both laterally and vertically. In general there is a coal free basal portion with some marine intercalations, 146-325 feet thick, overlain by from 300 to 750 feet of shales, sandstones and grits with several seams of workable coal, overlain by a variable thickness of coarse sandstones with some marine fossils similar to those below the coals. Associated with the coal is an extensive flora, first made known by Engelhardt.[35] This now comprises over 100 species, the most prominent families being the Leguminosae, Rutaceae, Dilleniaceae, Flacourtiaceae, Lauraceae, Myrtaceae, Apocynaceae and Rubiaceae. This flora contains no elements of the existing flora of central Chile but consists, in the main, of representatives of the existing flora of the montaña region of the eastern Andean slopes north of central Bolivia. This flora is clearly lower Miocene in age and serves to confirm the lower Miocene age of the Navidad marine fauna, although it should be noted that the marine fauna associated with the coal measures is limited and the bulk of the Navidad fauna comes from farther north (Navidad is in Latitude 34° S.). It is quite possible that the Navidad as a whole should be correlated with the Aquitanian and Burdigalian stages of European geology. There is no basis for considering it Oligocene in the typical sense and the very prevalent notion that it corresponded with the Tejon of California (De Lapparent calls it Sparnacian) rested on mixed collections from Navidad and underlying upper Cretaceous, and the failure to recognize the obvious unconformity between Mesozoic and Cenozoic in local sections.

[34] Steinmann, G., Neues Jahrb. Beil., Bd. 10, p. 1, 1895.
[35] Engelhardt, H., Abh. Senck. Naturf. Gesell., Bd. 16, Heft 4, 1891.

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The second Tertiary marine horizon is that of the so-called Coquimbo stage of Steinmann,[36] named from exposures near Coquimbo (Latitude 30° S.) and probably the same as those at Caldera (Latitude 27° 4′ S.) and elsewhere in the coastal region, as at La Cueva. Some shell marls north of Arauco contain a fauna which suggests that they are to be referred to the Coquimbo stage.

At Coquimbo the deposits are intercalated soft, often calcareous, sandstones, marls, sands and conglomerates. The maximum thickness is about 200 feet. The known fauna[37] consists of about 60 species nearly all of which are extinct forms, but closely allied to the existing fauna of the Pacific Coast region and regarded as Pliocene in age. The Coquimbo is overlain in places by marine beds constituting the Valparaiso stage of Steinmann and of Pleistocene age. Outcrops of the Coquimbo stage were referred to by d'Orbigny, Darwin, Gay, Hupé and others and were formerly rather generally regarded as Miocene.

Continental deposits of uncertain age, and ranging from Tertiary to recent, form much of the desert country lying between the Andes and the coast. A considerable number of the familiar Andean types of mammals (Scelidotherium, etc.) have been described from Tarapacá and elsewhere southward to Patagonia.[38] Lignitic strata have been recorded by numerous travellers throughout southern Chile to Tierra del Fuego, and there has been a tendency, as exemplified by Brüggen to regard them as a southward continuation of the Concepcion-Arauco Coal Measures. This is rendered doubtful by the section discovered near Punta Arenas and identified at various localities in southern Patagonia and Tierra del Fuego. These beds have been described by Ortmann, Hatcher, Nordenskiöld, and others, and are of especial interest to the students alike of paleobotany and continental history.

The section, somewhat abbreviated, is as follows:

1. Sands, lignitic sandstone, and conglomerates = horizon V of Hatcher = Patagonian formation of Ortmann = Burdigalian;
2. Sandstones with lignite beds and fossil plants = horizon IV of Hatcher = Upper lignites or Punta Arenas coal Miocene Araucaria beds of Dusén = Acquitanian;
3. Sandstone with oyster beds = horizon III of Hatcher = Oligocene;

[36] Steinmann, G., Neues Jahrb., Beil. Bd. 10, pp. 533-547. 1896.
[37] Möricke, W., op. cit.
[38] Nordenskiöld, E., Kgl. Svensk. vetens-akad. Handl. Bd. 33, No. 3, 1900.

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4. Sandstones with fossiliferous calcareous lenses = Oligocene;
5. Fossiliferous beds = horizon II of Hatcher = Oligocene;
6. Sand and sandstone with fossiliferous calcareous concretions and fossil plants = horizon I of Hatcher = Oligocene Fargus zone of Dusén = Oligocene;
7. Lignitic shales = lower lignites of Hatcher = Oligocene.

This section presents the record of a minor oscillation of the strandline with continental deposits passing into lagoonal, and these into littoral and shallow-water marine, and then gradually shallowing and perhaps becoming emergent during the Aquitanian, followed by a marked transgression in the Burdigalian. At present our chief interest centers in the Fagus zone and its flora. This flora, as described by Dusén,[39] consists of 29 species, of which a Flabellaria of doubtful validity is the only one that occurs in the Tertiary floras already enumerated from South America. The particular facies of this flora is furnished by the abundance of Fagaceae. This family is represented by two species of Fagus and by 13 species or varieties of Notho fagus. This flora is certainly older than those already mentioned and it is as certainly Tertiary in age. It unquestionably had its beginnings in the northern hemisphere and has also been found to be represented at somewhat similar horizons in Australia, New Zealand, and Antarctica. That it did not migrate into Patagonia from North America appears to be probable from the absence of any definite ancestral assemblage in the abundantly fossiliferous Upper Cretaceous or Eocene of the latter continent from which it seems probable that it could have been derived. Nor are any traces of it found at more northern localities in South America. The explanation seems to be that it reached southern South America from the opposite direction, namely, Antarctica.

A very interesting Tertiary flora has been recently described[40] from the border of the Antarctic continent on Seymour Island, off the east coast of Graham Land. This flora contains a large element of subtropical types like those found today in southern Brazil, and another large element of forms suggestive of the existing temperate flora of southern Chile and Patagonia, and including species of Fagus and Nothofagus like those found in Patagonia, Chile, Australia and New Zealand. Dusén, ignor-

[39] Dusén, P., Ueber die tertiäre Flora der Magellansländer; Svenska Exped. till Magellansländerna, Band I, pp. 87-107, pls. 8-13, 1899.

[40] Dusén, P., Über die Tertiäre Flora der Seymour-Insel. Wiss. Ergeb. Schwed. Süd-polar-Exped.: 27 pp., 4 pls. Band 3, 1908.

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ing the usually mixed climatic character of early Tertiary floras, and the association of tropical and temperate types under favorable conditions of humidity, and basing his conclusions on the broken character of the fossil remains of these temperate types, reached the conclusion that the temperate and the subtropical elements were contemporaneous, but that the latter were coastal forms under a subtropical climate, while the former grew in the vicinity at elevations which he suggests amounted to 6500 feet or more, and were brought by streams to the littoral basin of sedimentation. If this is true, it indicates a considerable mountain chain of the Andean type forming the axis of Graham Land at that time as it does at present. The only evidence bearing on the age of the folding, which may really have little bearing on the time of elevation, is the presence at Hope Bay, on Graham Land, of an extensive late Jurassic flora[41] found in continental beds which are involved in this folding. Dusén concludes that this Tertiary Antarctic flora is older than that of the Fagus zone of the Magellanian beds.

Poorly preserved mollusks associated with the plants are considered by Wilckens to represent what he calls the Patagonian Molasse, but since the latter is more or less composite, as Windhausen[42] has shown, and includes faunal elements belonging to the lower Eocene San Jorge formation as limited by the latter author, the evidence for the correlation adopted by Andersson[43] can not be said to be conclusive. The presence of Zeuglodon vertebrae, described from this locality by Wiman, should probably be considered as evidence of Eocene age. I would therefore dissent from Wilcken's conclusions that this plant-bearing sandstone is upper Oligocene or lower Miocene in age and would consider this flora as of middle or upper Eocene age.

As shown on the accompanying diagram the writer regards the Fagus zone of the Magellanian, as Ortman christened these beds, as probably Eocene and the Araucaria zone as probably Oligocene.

[41] Halle, T. G., The Mesozoic flora of Graham Land: Swedish South Polar Exped., 1901-1903, Band 3, lief 4, 123 pp., 9 pls., 1913.

[42] Windhausen, A., The problem of the Cretaceous-Tertiary boundary in South America and the Stratigraphic position of the San Jorge formation in Patagonia: Am. Jour. Sci. (iv), vol. 45, pp. 1-53, 1918.

[43] Andersson, J. Gunnar, On the geology of Graham Land. Bull. Geol. Inst. Upsala, vol. 7, pp. 19-71, pls. 1-6, 1906.

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ARGENTINA

The age of the Argentine Tertiaries have been ably discussed within the last 15 years by Ameghino, Roth, Gaudry, Scott, Hatcher, Ortmann, von Ihering, Wilckens, Cossmann, Wiman, Matthew, Windhausen and others. A review of formational names proposed and correlations suggested would be too lengthy as well as somewhat outside the scope of this paper. The following summary of the more important terms in the form of a diagram of the movement of the strand must suffice in the present connection. (See fig. 1.)

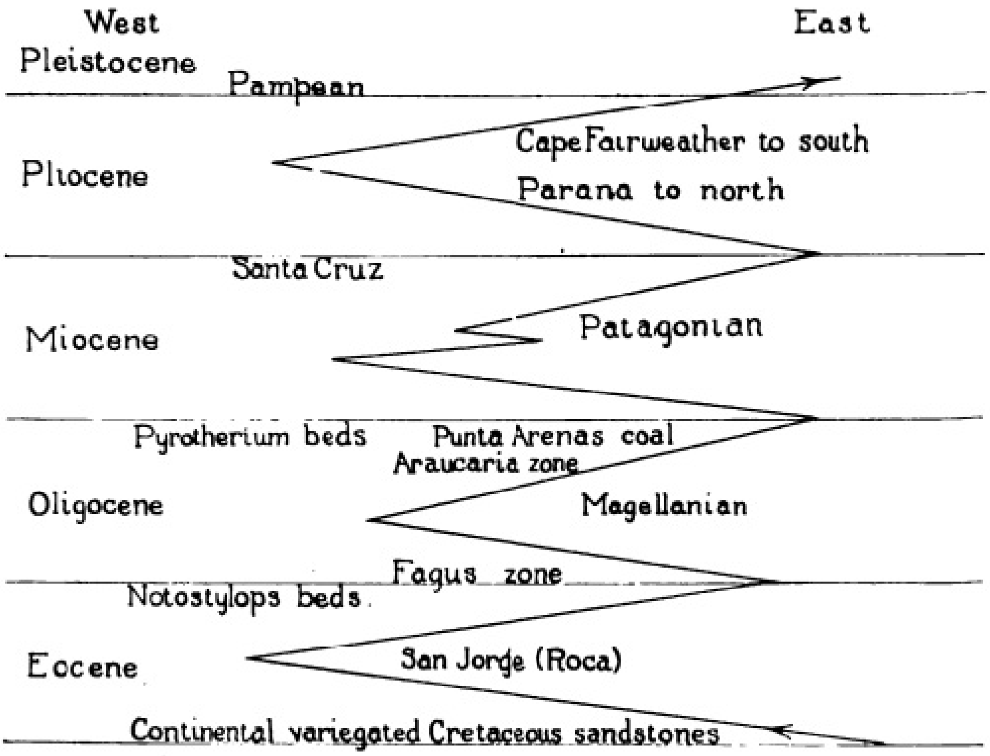


FIGURE 1. Generalized diagram of the Tertiary movement of the strand in southern Argentina.

It is interesting to note that although a barrier between Chile and Argentina in the Andean region is indicated by the western limits of the San Jorge and Patagonian seas, by the contrasted climate east and west of this barrier at the time of the Navidad flora, and by the volcanic material in the Argentine continental deposits, the marine Cape Fairweather beds exposed at sea level on the Straits of Magellan are involved in the Andean structure and elevated to a height of 5000 feet at no great distance to the northwest in the Andean chains (Hatcher).

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GRAHAM LAND

The results of the Swedish Antarctic Expedition have made known a considerable section on the shores of the Antarctic which shows a remarkably similar sequence to that along the South American coast. A brief summary shows that following marine conditions and a rich Indo-Pacific Ammonite fauna of upper Cretaceous age there was emergence toward the close of the Cretaceous, as in Patagonia and throughout all of the South American coasts. A positive movement of the strand long after the dawn of the Eocene is shown in Graham Land by littoral sediments with fossil land plants followed by emergence in Oligocene time. The Burdigalian, a time of transgression on both coasts of South America is possibly represented by a part of the younger Seymour Island beds of Andersson. A third emergence (upper Miocene) is succeeded by the Pecten beds which may represent the Pliocene marine beds of South America.

CORRELATION OF FORMATIONS

The following table, Table I, summarizes the existing knowledge of the relations of the Tertiary sediments of western South America.

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TABLE I. TENTATIVE CORRELATION TABLE OF WESTERN SOUTH AMERICAN TERTIARY

Europe	Southeastern United States	Panama	Colombia	Ecuador	Peru	Chile	Patagonia
Pliocene	Pliocene	Toro	?	Paita ?	Paita	Coquimbo Caldera	Parana Cape Fairweather
Upper Miocene	Upper Miocene		?	Talara ?	Talara		Santa Cruz
Tortonian	Chesapeake						Santa Cruz
Helvetian		Gatun	Marine & Plant Beds	Zorritos Loja coal	Zorritos	Navidad	Patagonian
Burdigalian	Alum Bluff			?			Pyrotherium
Aquitanian	Tampa Chattahoochee	Culebra Emperador & Bohio	?		Heath	?	
Oligocene	Vicksburg				?		Magellanian
Upper Eocene	Jackson		Arroyo Hondo		Lobitos		Notostylops San Jorge
Auversian Lutetian	Claiborne	Tonosi			Negritos		?
Ypresian Sparnacian	Wilcox				?		
Thanetian Montian	Midway						

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THE BASIS OF THE CORRELATION OF POST-CRETACEOUS FORMATIONS OF THE PACIFIC REGION

By T. Wayland Vaughan

INTRODUCTION

As the standards of geological chronology were first established in Europe, where geology had its birth, geological events that transpired in other parts of the world must be dated with reference to those standards. But before European standards can be applied elsewhere with assured correctness, it is necessary to establish essential contemporaneity of events, in other words make geological correlations.

The more important criteria used in geological correlation are as follows: (1) Stratigraphic criteria which include continuous tracing of formations by lithologic features, the significance of lithologic characteristics, and the superposition of formations; (2) biological; (3) diastrophic; (4) climatic; and (5) physiographic criteria.

It would be pertinent to discuss here the limits of the applicability of each of these sets of criteria and particularly to point out the weaknesses of each set, but to do so would require more space than should be devoted to this paper. The areal limitations of criteria based upon stratigraphy, diastrophism, climatic changes, and physiography are known to all geologists and the mention of these limitations is sufficient. One of the defects of biological criteria will be mentioned. It is the assumption in the Lyellian method of classifying Tertiary marine deposits according to the percentage of species still living, that the rate of organic change is the same for all parts of the earth. There is very good reason to believe, as has been made evident in several of the preceding papers of this set, that the rate of organic evolution has not been the same everywhere, and that, specifically, change has been slower in the tropical Pacific and Indian oceans than in temperate climates and in the warmer parts of the Atlantic. There are other defects or limitations in the biological method but they will be passed without consideration.

When all methods and criteria of correlations are admitted to be defective by those who have carefully studied the subject, the question naturally arises, how can a convincing result be

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obtained? This seems possible only by combining different sets of criteria, except in regions where continuous tracing of formations within the same ecologic province is practicable.

As the margins of the Pacific and the islands within its confines are remote from Europe, direct tracing is out of the question, but two possibilities are present. One is to correlate with Asia and work westward across it to Europe; the other is to correlate with America and through it to correlate with Europe. But it will soon be made evident that the entire problem cannot be solved in this way and that additional criteria must be utilized.

CORRELATION BY WAY OF ASIA

The possibility of correlation by way of Asia is indicated on the paleogeographic maps of de Lapparent and Haug. According to these authors the Atlantic Ocean was in communication with the Pacific by the Tethys Sea of Suess, during Eocene time, and they believed communication continued through a part, if not all of Oligocene time. But it is highly improbable that there was any such marine connection during Oligocene time, although several paleogeographers represent a continuous water way from the eastern Mediterranean to the Pacific. The inference from Wadia's[1] summary of the geology of India is that the sea retreated from the Himalayas during later Eocene time.

Martin has apparently given definite evidence as to the time when the East Indies were cut off from marine communication with the Mediterranean.[2] The evidence cannot be presented here, but his conclusions are as follows:

> Zur Zeit der Entstehung der eocänen Ablagerungen von Nanggulan, welche vorläufig an die Basis des oberen Eocäns gestellt sind, war das Gebiet des jetzigen Java vollständig von Tethys losgelöst und seitdem ist die Verbindung mit letzterer auch niemals wieder hergestellt, obgleich während der ganzen Tertiärperiode eine ununterbrochene Senkung in der malayischen Geosynklinale statt fand.[3]

He also says:

> Die Fauna des älteren Neogens der Malayischen Region ist den gleichaltrigen von Europa and von anderen Gegenden noch verwandt.

[1] Wadia, D. N., Geology of India for students: 398 pp., 20 pls., 37 text-figs., Macmillian and Co., London, 1919.

[2] Martin, K., Wann löste sich das Gebiet des Indischen Archipels von der Tethys: Samml. geol. Reichs-Mus. Leiden, ser. 1, vol. 9, pp. 337-355. 1914.

[3] Op. cit., p. 353.

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was unter anderen durch die Foraminiferen zum Ausdruck kommt; die Fossilien des Neogens führen dann allmählich zu den heute noch lebendenen Arten des Indischen Archipels hinüber. Wenngleich wohl stets ein Austausch mit benachbarten Gebieten Stand fand, *so darf man doch die ganze tertiäre Fauna der heir behandelten Region im wesentlichen als autochthon betrachten.*[4]

Besides the eastward extension of the Atlantic through Tethys there was communication with the Arctic Ocean by means of an arm over the Caspian and Aral Seas and the Ural Mountains during Eocene time and it persisted during Oligocene time, but the connection of Tethys with the Arctic probably did not cause any migration of organisms from the Atlantic to the Pacific by an Arctic route. During Miocene time Tethys no longer existed and communication between the Atlantic and Arctic by way of the Aral and Caspian Seas was closed.

From what has been said of marine faunas, tracing from Europe to southeastern Asia is possible for early Eocene, but it is not possible for later Eocene, Oligocene, and Miocene time.

More use should be made of terrestrial organisms in correlating along the Asiatic littoral than has yet been done and the work of Matsumotu on the fossil vertebrates of Japan,[5] Mansuy on those of French Indo-China,[6] and others on the fossil vertebrates of eastern and southeastern Asia deserves special commendation. Results in Asia comparable in value to those obtained by Merriam in California and Sellards and Merriam in Florida may be confidently expected. I have not been able to study the literature on Asiatic terrestrial organisms sufficiently to ascertain how much assistance they can at present give in determining the geological age of marine strata.

CORRELATION BY WAY OF AMERICA

The possibilities of correlation by way of America will be introduced by mentioning two inferences regarding the paleogeography of western Europe and the North Atlantic Ocean.

The first of these appertains to climate. Haug[7] says:

Near the beginning of the Nummulitic period, during the Thanetian, we have numerous proofs of the arrival of relatively cold water as

[4] Op. cit., pp. 354, 355.

[5] See paper by Professor Yabe in this volume.

[6] Mansuy, H., Sur quelques mammifères récemment découverts en Indochine: Serv. géol. de l'Indochine Mém., vol. 5, 26 pp., 6 pls., 1916.

[7] Traité de Géologie, vol. 2, pp. 1565-1566.

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far as central Europe. . . . During the Londinian we find again the greater part of the boreal elements of the Thanetian . . . .

During the Mesonummulitic period, warm currents introduced into the Anglo-Parisian basin, by way of the English Channel, a fauna the greater part of whose species appear to be of Mediterranean origin.

The data regarding the Miocene climate of Europe are meager according to Haug, but the temperature of the sea during Aquitanian time in southern Europe was warm. Farther north but later in the Miocene, on the shores of England and the low countries the number of species characteristic of the present Arctic Seas steadily increases from the beginning to the end of the Neogene.[8]

Although the amount of information on the Tertiary climate of Europe may be small there is enough to show both climatic zoning and climatic oscillation. The climatic oscillations parallel rather closely, if not precisely, those during Tertiary time in the southeastern United States.

The other feature of the Tertiary geography of Europe to be mentioned is that according to Haug during Eocene time there was either shallow water or actual land connection from Scotland and Ireland to North America, and this explains the near affinities between the shoal-water middle Nummulitic faunas of the Atlantic slope of the United States and those of the Paris basin.[9] During Miocene time, although North America continued to form a part of the North Atlantic continent, Europe was separated from it probably by an arm of the sea which lay between Spitzbergen and the Finno-Scandinavian massif and emptied into a gulf now covered by the North Sea.[10] There was during Miocene time, according to this hypothesis, an opportunity for the migration of littoral faunas between northwestern Europe and northeastern North America.

The status of the correlation of the marine formations of eastern North America, the West Indies, and Central America has been summarized in a preceding paper of this series. It seems that most of the correlations through the Eocene and lower Oligocene are essentially exact, and that the probable limit of error in the correlations from middle Oligocene to Pliocene is that of one stage. For instance, it is possible that

[8] Haug, E., Traité de géologie, vol. 2, p. 1733.

[9] Haug, op. cit., p. 1559.

[10] Haug, op. cit., p. 1732.

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what I am correlating with the Rupelian of southern Europe might be Chattian. In America as in Europe there are two climatic provinces, a warm water fauna in the south and a temperate or cool water fauna in the north. Fortunately the two provinces meet in Florida and there was climatic oscillation which caused retreats and advances of the two faunas, so that it has been possible to ascertain their stratigraphic relations. It has also been possible to correlate the cool water faunas of the Atlantic coast of the United States with cool water faunas of western Europe and to correlate the warm water faunas of the Caribbean region with the warm water faunas of the Mediterranean region of Europe.

The next step to be taken is the consideration of the connections between the Atlantic and Pacific oceans across Central America during Tertiary time. Recent studies in Panama, Costa Rica, and Nicaragua, have shown that there were in that region connections between the two oceans during middle and latest Eocene time, middle and latest Oligocene time, and oldest Miocene time. I have also pointed out that there was at some place probable connection between the oceans during very late Miocene or even Pliocene time. Present information indicates that there was connection between the Atlantic and Pacific across Central America at a very much later date than the last connection from the eastern end of the Mediterranean across Asia. It is therefore highly important that the fossil marine faunas of the tropical Pacific lands should be compared with those of Central America and the West Indies. It is very probable that the presence of similar organisms in post-Eocene formations of the East Indies and Europe is due to migration from the Atlantic to the Pacific or *vice versa* by way of American inter-oceanic connections.

To one experienced in the study of living Atlantic and Indo-Pacific and the Tertiary marine faunas of Europe and tropical and sub-tropical America, certain relations, first recognized long ago, become increasingly more impressive. These relations, which have been discussed to some extent in a preceding paper by me in this series, are as follows: (1) The living Atlantic fauna is in many respects strikingly different from the Indo-Pacific fauna; (2) The two faunas were not differentiated from one another in Oligocene time and they were

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only slightly differentiated in the Miocene. This is true of the Oligocene of Europe as well as of the Oligocene and Miocene of the West Indies and Central America.

RESULTS EXPECTABLE FROM CORRELATIONS ACROSS ASIA AND ACROSS AMERICA

1. Correlation of early and middle Eocene formations in Pacific lands should be possible by comparisons with either Europe, Asia, or America.

2. Correlation of Oligocene and older Miocene formations can probably be made by reference to the American Caribbean region as the standard, if in the south the work is carried northward from southern South America and if in the north an effort is made to tie to the western coast of the United States. More data on the stratigraphy and paleontology of western South America are urgently needed.

3. The correlation of the later Miocene and younger deposits of the Pacific must be made by means of other criteria which will now be discussed.

INTERPOLATIONS BETWEEN OLDER MIOCENE AND RECENT

As correlations based on direct comparison of Pacific marine faunas of later date than old Miocene with European or Caribbean faunas are not possible, recourse must be made to the following methods:

1. Later Miocene and Pliocene formations must in large measure be correlated by interpolation based upon the degree of faunal similarity or dissimilarity to older Miocene and to Pleistocene and Recent marine faunas. In dealing with later geological formations physiographic criteria may be of great assistance, but again the principle of relative age and interpolation must be applied.

2. The possibility of fixing the age of later Tertiary marine deposits along the Pacific shores of both Asia and America by the utilization of terrestrial organisms should be given attention, because if deposits of similar age occur in the islands, the insular marine formations may be correlated with the formations of ascertained age on the continents.

3. The definite identification of deposits in the tropics as of Pleistocene age is difficult, for in that region there are no direct records of glaciation, and Pleistocene marine invertebrate

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faunas differ only slightly or not at all from the living faunas. Although the faunas should be studied with great care and compared with older and younger faunas, the evidence that will probably be of the greatest value in correlation is physiographic. The possible effects of glaciation and deglaciation on lowering and raising sea-level, particularly in the tropics, are based on principles so sound that there seems to be no escape from the conclusion that changes in the height of sea level must have been produced by such causes. Changes in sea level produced by glaciation and deglaciation should have left physiographic records, at least some of which may reasonably be expected to have been preserved. Very accurate study of the physiography of the Pacific lands is important for many reasons, one of which is the assistance such a study may render geological correlation.

CONCLUSIONS

The following suggestions are made regarding investigations needed for adequate correlation of the geological formations and their associated phenomena in Pacific lands:

1. All investigators will agree that the first essentials are detailed studies of the fossil biotas and their stratgraphic relations and comparisons of the biotas with European, Asiatic, West American, and Caribbean biotas of ascertained age on one hand and with the living Indo-Pacific biota on the other.

2. Other essentials are monographic accounts of the Tertiary biotas of the Caribbean region. Although steady and rapid progress has been made during the past few years in the study and description of these biotas, not enough has yet been published to supply an adequate basis for the elucidation of the formations of the Pacific. Several volumes have recently been published on Caribbean paleontology, the manuscripts for several other volumes are awaiting publication, other volumes are in preparation, and others are planned. Geological surveys of several West Indian islands are being made and they will yield additional useful information, but provisions are not yet sufficient to meet the demands for information on the region. The Caribbean region is a geological key region of the world, in some respects transcending in importance the great Himalayan geosyncline.

3. Although I am not in a position to review knowledge of all the groups of organisms represented in the Tertiary

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deposits of Europe, I can speak with assurance regarding corals. The Tertiary corals of Europe urgently need critical revision by someone familiar with that entire group of organisms. Descriptions of species by paleontologists working on local faunas or faunules do not suffice. Knowledge of some other groups of organisms is, I believe, in more satisfactory condition, the foraminifera, echinoids, and Mollusca, for instance, but catalogues of genera and species giving precise localities and the stratigraphic position of each species would be very helpful to investigators working outside Europe.

4. Without having made an exhaustive study of the original sources, but from reading several summaries, the impression has been made on me that the marine deposits of ages subsequent to later Eocene in India and other parts of southern Asia need far more study than they have yet received. It is possible for the geologists of the Indian Survey to help in the solution of the problems of the Pacific by presenting a summary of available information on the Tertiary stratigraphy, paleontology, and paleogeography of southern Asia, by clearly pointing out wherein information is inadequate, and by undertaking to obtain data to fill the recognized deficiencies.

5. The value of the study of terrestrial organisms in fixing the age of marine deposits on the continents has been mentioned.

6. Fossil biotas of Tertiary and later age cannot be properly interpreted without full knowledge of living biotas. Therefore, it is of prime importance in the study of the fossils of the Pacific to have as complete information as is possible on the living organisms of the Pacific. The value of knowledge of the Caribbean region in understanding the Pacific has been pointed out. In order better to understand the fossil biota of the Caribbean region, and through it the Pacific biotas, knowledge of the living Atlantic biotas needs to be more intensive.

7. The importance of the intensive study of the physiography of the Pacific islands has been mentioned. In my opinion some of the problems of geologic correlation can be solved only by combining the results of physiographic investigations with those obtained through stratigraphic and paleontologic researches.

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MISCELLANEOUS PAPERS ON GEOLOGY

THE FRAMEWORK OF THE PACIFIC

By E. C. Andrews

(Note: Mr. Andrews led the discussion with a brief statement dealing with the structural unity of the suboceanic mass of the Pacific Ocean, together with the margins of the various continents facing that ocean. He pointed out that Dr. T. C. Chamberlain many years ago from general principles had considered the suboceanic mass of the Pacific as forming a structural unit. During the past fifteen years Mr. Andrews has been led to consider the massif under consideration as forming a geographical and geological unit for a considerable period. The arrangement of the topographic features indicated this unity as dating back to the Cretaceous at least, whereas the geological structures within and around the Pacific indicated the structural unity of the massif from the present time to a period remote in geological time. He proposed only to supply the evidence in this connection as far back as the Cretaceous, and he would leave the proof of this unity in times still more remote to Drs. T. C. Chamberlain, T. Wayland Vaughan, Warren Smith, and N. Yamasaki. The work of Drs. T. A. Jaggar, W. Bowie, F. Omori, and H. O. Wood, also supported the idea of Pacific unity strongly from the point of view of structure. The evidence adduced by Mr. Andrews was then presented.)

The Pacific Ocean may be regarded as forming two portions, an eastern and western one. The true margin on the east may be considered to be the western edge of the American continent, thence to the south it turns easterly by Cape Horn to Antarctica, thence to the west and north by way of the Antarctic Islands, New Zealand, Tonga, the island arcs lying north and northeasterly of Australia, the Philippines, Japan, thence through the Aleutian Islands to the American continent. Marshall, of Dunedin, has made an illuminating statement in this connection[1] for the southwestern portion of the Pacific.

The eastern portion of the Pacific is almost free from islands, whereas the western, and especially the southwestern portion, contain many island groups. These islands have a peculiar disposition. They are arranged in arcs of curves, which follow the general curvature of those margins of the continents fronting the western Pacific, and to which they are nearest. Thus New Zealand, the New Hebrides, and the associated groups, conform geometrically to the eastern curve of the Australian continent, the Philippines and Japan to the neighboring

[1] P. Marshall, Proc. Australian Assoc. Adv. Sci., Sydney, 1911.

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curve of Asia. The Hawaiian and Samoan arcs conform generally to the northwestern margin of the Americas and to the Australian curve.

Another point of great interest also is the disposition and the elevation of recent coral limestone. In the eastern Pacific raised coral reefs, apparently of Pleistocene age, are almost absent. In Hawaii they have been recorded a few feet above sea level, so also for the Samoan and Society groups. In Tonga raised Pleistocene reefs occur at least 400 to 500 feet above the sea; in Fiji they have been recorded as 1000 feet above the sea, while in the more western island arcs they have been recorded up to 2000 feet above the same datum. On the mainland of Australia the extreme elevation of recent coral reefs is only a few feet.

Considerable submergence is indicated also for this more western portion of the Pacific as recorded by borings for artesian water on the Hawaiian group and by coral reef boring at Funafuti by David and others. The sum total of these Pleistocene movements, however, indicates a decided stability for the eastern Pacific, and a great development of sunken and raised blocks in the western Pacific, the margins of the associated continents in the west being in a condition, relatively of stable equilibrium.

Turning to the marginal areas of the Pacific, it may be noted that the great deeps are to be found in this region. They occur not as broad sunken areas, but rather as narrow zones whose longer axes lie near, and sub-parallel, to the western shoreline of America and the eastern lines of the island arcs in the western Pacific.

Professor Omori has shown that strong earthquakes follow these deeps in the Pacific area. He has also shown that the main volcanic zone of the Pacific lies on the continental side of these deeps and earthquake zones. The earthquake zones form arcs presenting their convexity to the ocean, whereas the volcanoes lie on the concave portions of these ocean deeps and earthquake zones. Other shorter and sub-parallel zones lie within the Pacific, such as the Hawaiian and Samoan examples.

The continental and island shelves come next for review. Each of the continental margins fronting the Pacific and each of the larger islands in the western Pacific, has a submarine shelf whose outer margin varies from 600 feet (or 400 feet. according to T. Wayland Vaughan) below the ocean surface

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Beyond this depth the profile steepens markedly to ocean depths. In the neighborhood of the great deeps and of the high plateaus the continental shelves are narrow, whereas in the neighborhood of low plateaus the shelves are wider.

An interesting point also is the fact that all the river mouths which discharge into the Pacific within the equatorial and temperate regions have been submerged in recent times. The amount of such submergence has not been ascertained. For the eastern part of Australia it appears to be about 200 feet.

The next point to be noted is that all of the continental margins, and all of the island arcs sub-parallel thereto, consist of plateaus variable in height. On the American side the plateaus are lofty. The island arcs themselves may have lofty plateaus, but they appear to have been broken and tilted, thus giving heights very variable for these plateaus. The plateaus again on the continental margins of the western side of the Pacific are not lofty except in rare instances. This indicates a relative instability for the western portion of America and for the island arcs, inclusive of Hawaii and Samoa. It indicates also a relative stability for the Australian and Asiatic continents on the Pacific side, except at the area where the Himalayan and Malaysian zones of folding connect with the Pacific zones of uplift.

What is the age of these plateaus? After due allowance has been made for the variable nature of the rocks of which they are formed, it would appear that the continental margins are all in the same stage of stream dissection. From an examination of the important streams, such as the Murray, the Columbia, and the Colorado, it would appear that the formation of the plateaus must be several millions of years old. The plateaus again were not uplifted at one stage, but were formed during several revivals of uplift during one geological period. This girdling of the Pacific with plateaus, all in a similar state of dissection, is a strong indication of the unity of the Pacific itself in late Cainozoic and post-Cainozoic time. The main island plateaus are also well dissected by stream action, but many of the smaller islands form plateaus of later Pleistocene age.

It is interesting to note also that late Cainozoic folding and tilting occur on the western margin of America, and on many of the island arcs, whereas no movement such as this appears to have been recorded for Australia and Asia, except

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at the junction of the Himalayan and Pacific lines of structure in southeastern Asia. This indicates a greater stability of earth structure in the eastern Pacific, and a tendency for the western Pacific to be much less stable, the zones of folding and fracture retreating to the east from the older land masses and leaving the continents in a state, relatively, of stable equilibrium.

The next stage for Australia, at least, and probably for the United States also, was a period in which the land was dissected to the stage of late maturity and then raised. Thereupon the streams cut deep valleys and these valleys in turn were filled with stream deposits and covered with floods of basalt from earth rifts. The period preceding this appears to have yielded a similar set of conditions. It is probable that the Asiatic and South American margins will have a similar story recorded for them in the future.

Coming now to the age of the chalk deposits of England and America, the Pacific Ocean appears to have spilled gradually over its margins. In the southwest the sea entered the north of Australia and almost effected direct connection with the southern ocean. The great sea over North America connected the Gulf of Mexico with the Arctic Ocean, leaving a long land strip to the west. In South America a similar condition of events occurred.

From the foregoing remarks, it would seem thus that a case has been established at least for the geological unity, as far as the facts of form around the Pacific Ocean margin are concerned and as far back in time as the Cretaceous. Beyond this period the case for Australia could be carried, and it would be of great interest to have the opinion of Dr. R. T. Chamberlin in the case of America.

Before leaving the consideration of the unity of the Pacific, as far as facts of form are concerned, it would be interesting to draw attention to some other interesting details in their distribution. Thus, the eastern side of Australia is convex to the Pacific. Asia also presents arcs of curves which are convex to the Pacific. So also do the island arcs. Each convex arc is connected with a curve concave to the Pacific. This is shown well at the junction of the Asiatic and the Pacific lines of mountain growth in later geological time. It is also especially well shown on the American side. The great Aleutian arc is concave to the ocean and this is succeeded to the south by the

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convex curve from British Columbia to Central America. Thence T. Wayland Vaughan has shown that the Antillean lines are connected with some great east and west zone of weakness in the Mexican Gulf and the Caribbean Sea, producing thus a concavity to the Pacific which is reflected somewhat mildly in the Central American curve concave to the Pacific. To the south this passes into the great convex form of Peru and Bolivia with the concavity of Chile, and the great concave form passing eastwards by way of Cape Horn.

A smaller structural unit within the Pacific may be mentioned here, as it appears to be a type of the western Pacific structures. America tells a similar tale, according to Dr. T. C. Chamberlain, but the suboceanic mass appears there to have been more resistant and the various mountain-forming zones have kept more closely together, whereas in the western Pacific the sea has rolled into the inter-montane zones.

Thus in Australia and New Zealand with New Guinea, and the associated islands, there is a five-fold division of geographic forms. In western Australia a low plateau [1] exists which rises from 1000 feet above sea level near Perth to 2000 and 2500 feet toward the northeast. This block is solid. Its surface is only roughened slightly. It is not traversed by structural gaps and it is broken only on its northern and northeastern portions by heavy faults.

Central Australia consists in the main of a low-lying plain, a portion of which is slightly below sea-level. Large fault blocks occur within this area, such as the Mt. Lofty, Flinders, McDonnell, Barrier, and other ranges, some running east and west, others north and south. A series of high plateaus forms the eastern side of Australia, but they are much higher than those of west Australia and they are much narrower and are broken up with low gaps through which railway tracks have been constructed. These gaps are radial, from the southwest of Australia, towards the northeast. Beyond the eastern margin of Australia, deep sea occurs, while beyond this to the east and the north lie the arcs of New Zealand, New Caledonia, the Solomons, New Guinea, and the associated islands. Here the plateaus are both very high and very narrow, but in contradistinction to those of eastern Australia, they are separated by

[1] Jutson, J. T., Physiography of Western Australia, Dept. of Mines Bull. 61, 1914.

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ocean depths which indicate the breaking and sinking of portions of once continuous land masses. These ocean gaps are also radially disposed as from southwestern Australia to the northeast and east.

What then is the significance of these observations?

Assume in the first place the structural unity of the sub-oceanic mass of the Pacific to the earth's center as outlined by Dr. T. C. Chamberlain. This mass is heavier than the surrounding earth's surface and is thus sinking as opportunity offers.

The first items of importance to note in this connection are:

1. The freedom from pressure of the mass at the surface, except for the atmospheric weight, which is negligible in this connection;

2. The lack of escape from pressure of weight in those portions of the sector lying beneath the crust or at a depth, say exceeding 50 to 100 miles from the surface;

3. The exceedingly short bond or grain of the rocks forming the crustal portions as compared with the dimensions of the sub-oceanic sector;

4. The depth at which rock masses would flow under their own weight if unsupported at one or more sides;

5. The depth at which they would flow if completely supported on all sides.

Of these, the first is so important as naturally to compel the attention of engineers were they to study a subject such as this. Nevertheless, this lack of support at the surface of the earth appears to be the point generally neglected by geologists in discussions as to manifestations of force at the surface. Dr. H. O. Wood has informed me verbally also of the common neglect of this factor in discussion as to the strength of earth's structures.

It is evident also that if a material such as water, iron, or rock is completely supported on all sides it will not flow, but will merely tend to fill small natural cavities existing within itself. On the other hand, if an avenue of escape from extreme pressure be presented to it, it will flow in this direction.

If a cube of rock with an edge of fifty miles be placed upon the earth's surface, the lower portions would flow under the weight of its own mass.

Now, in the rock mass underlying the Pacific, there is then a peculiar action in progress at a depth below the surface.

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which we can estimate at less than 100 miles, there is a strong tendency for the rock masses to flow to the unsupported portions, that is, to the surface and to the margins where the material is lighter and weaker. If the crust be composed of tough material well bonded, there would tend to be no superficial manifestation arising from the resistance set up at the zone of possible flowage, but as the crust is composed of short-grained and friable rock masses, there will be a strong tendency for the material below to expand and flow toward the surface of the weaker portions of the coast. This manifestation would be in the nature of exceedingly slow flowage, or creep, towards the zones of weakness with sudden explosive release of strain when sufficiently close to the surface, or to a broad zone of weakness. This zone would lie at different depths from the surface. Below it the tendency would be less to escape from the surrounding pressure arising from superincumbent weight because of the great weight itself and the readjustment of forces below the brittle superficial rocks. Thus would arise the gradual creep of the continental margin towards the ocean in curves convex outwards with a lagging behind of stronger areas to form concave links of connection. Thus also would arise explosive relief of strain and creep long continued through zones such as that of the island arcs near Australia and Asia and through zones such as those along which the Hawaiian and Samoan islands are arranged.

There appears thus to be no necessity to differentiate the crust from the general suboceanic sector of the Pacific. It is simply that there is a tendency for the earth sector under the Pacific to flow on itself at a depth dependent on the strength of the superincumbent structures and in its evident aim to escape from its own pressure as weight to burst those structures at the surface where they are weakest. This suggests that isostatic compensation is not secured at a uniform depth, but rather that it is secured in a region which has an average depth perchance not exceeding 50 to 100 miles from the surface, and that the lighter masses are buoyed up over this region much as icebergs are buoyed up in water but that their bases lie at variable depths below the surface. Thus study suggests also that the margins and the western portions of the Pacific are relatively weak, but that the eastern half is relatively strong.

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THE BEARING OF GEODETIC INVESTIGATIONS ON THE GEOLOGIC STRUCTURE OF THE PACIFIC

By William Bowie

The geodetic work carried on by various government organizations has resulted in accurate geophysical data which promise to be of great value in the science of geology. These geodetic data result from field observations for the determination of the intensity of gravity and the deflections of the verticals.

The value of the intensity of gravity varies according to the latitude and to the elevation of the station above sea level. The gravity observation also varies from place to place according to the configuration of the ground, and deviations from normal densities of the earth's materials down to a limited distance below sea level. If corrections are applied which take into consideration the elevation of the station, the configuration of the ground, and the deviation from normal density, the observed values of gravity will agree very closely with the theoretical values.

A similar condition obtains for the deflections of the vertical. When triangulation, which gives accurate distances between widely separated points, is connected with astronomical stations, we have a means of determining the inclination of the plumb line from the normal direction that the plumb line would assume on a mathematical surface. We have a very remarkable case of the deflection of the plumb line on the island of Porto Rico. There is an astronomical station on the south coast, and another on the north coast, which have been connected by triangulation. The geographic position of the north station as computed through the triangulation from the south station differs from the astronomic position of the former station by 56″ of arc. The distance between these two stations in a north and south direction is approximately thirty miles. Therefore, the distance as computed from the astronomic data, differs by one part in thirty from the true distance.

The reason for this great discrepancy is the attraction of the mountain mass on the plumb line and the repelling effect on the south station of the deficiency of mass in the Caribbean Basin and the deficiency of mass in the Atlantic Ocean on the north station. No test has been made to show the effect of

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these positive and negative attractions but judging from the geodetic investigations in other lands, notably the United States of America, Canada, and India, it is reasonably certain that if corrections were made to observed astronomic positions at the stations in Porto Rico, the plumb line would be brought nearer to a normal position with regard to the mean figure of the earth. But there would still be discrepancies and these could be accounted for by assuming a deficiency from normal density in the material under the island of Porto Rico and an excess over normal density in the material under the Caribbean Sea and the ocean.

The geodetic investigations have shown that a condition of approximate equilibrium exists at a moderate depth below sea level. This condition of equilibrium has been given the name *isostasy*. It is not known how it is distributed under land masses and under water, but to make the computations practicable, a working hypothesis has been adopted so that the deficiencies and excesses of density are distributed uniformly throughout the column under any land feature, down to a depth of about sixty miles.

The results of the investigations indicate that no matter how the distribution of density is made, the effective depth of the compensating deficiencies and excesses of density is from thirty to fifty miles. When corrections have been made of the deflections of the vertical and the observed values of the intensity of gravity, to account for the effect of land masses, deficiencies of mass in the oceans, the deficiencies of density under land and the excess of density under the oceans, the observed values agree very closely with the theoretical values. The outstanding differences are never more than may be accounted for in local areas by an amount of material equivalent to about 2000 feet. Even this amount will probably be somewhat reduced because of extra light or extra heavy material near the various stations but below sea level. This matter has been treated in papers prepared by the author and by the former director of the Trigonometric Survey of India, Colonel Burrard.

It has been found that there is no relation between the anomalies of gravity and the deflection of vertical and the character of the topography. Therefore, we may assume that mountain masses, plateaus, and coastal plains are in the same state of isostatic equilibrium.

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It is generally recognized that isostatic conditions obtain to such an extent that it is reasonably certain that great masses such as continents and mountain systems are in isostatic equilibrium, and the logical conclusion seems to be that such mountain masses cannot be the result of general tangential movements, for if we had mountain masses resulting from tangential movements, they would be an excess on the earth's crust. The only conclusion that seems to be logical is that mountain masses are the result of some movement in the column below them which has forced them up. Such movement must be the result of changes in density in the column under the mountain mass for the region must have been in isostatic equilibrium before the formation of the mountain. The difference in the length of the column before the movement began and after it ended, is as much and often more, and it is evident that the only way to have a column lengthened without increasing its mass is to have a change in the density.

In a recent paper by Colonel Burrard, dealing with isostasy (Professional Paper No. 17 of the Trigonometric Survey of India), he came to the conclusion that the Ganges Plain is probably in an isostatic condition. He raises the question as to how such condition can exist when approximately 30,000 feet of sedimentary material has taken the place of an equal volume of material which was approximately 10 per cent greater than the density of the deposited matter. There seems to be only one answer, and that is that the column under the Ganges Plain has undergone a change which makes the density of the material greater than it was before sedimentation began. It would seem that there must have been actual sinking of the region as a result of increase in density in the column to supplement the depression of the area resulting from the deposition of material and the isostatic flow from this area of sedimentation.

When an area is sinking under sedimentation and a possible increase in the density of underlying material, it is reasonably certain that the column under this area is at least normal in its mass of material. It is illogical to assume that it is lighter than normal, for otherwise there could not be equilibrium. When sedimentation ceases and the column is in approximate isostatic equilibrium (and we may assume that it is, because the geodetic investigations show that existing areas of sedimentation are in this condition) then there must be a decrease in density in the

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column under the sediments when a mountain mass is formed over the column.

There are many geologic data to show that tangential forces have acted but it is believed that vertical movements forming mountain masses would result in horizontal forces near the earth's surface which could cause overfolding and overthrust; but this is a subject that need not be discussed at length in this paper. It is hoped that geologists will consider this matter of vertical movements and harmonize the geologic and geodetic evidence.

There are many geodetic data in existence today in the form of gravity observations and deflections of the vertical which could be reduced according to well-known methods and thus throw much light on the isostatic condition of the earth in new regions. It is especially desirable that this be done in Japan where excellent fieldwork has been done, in the Philippine Islands, and on some of the islands of the Hawaiian group. At an early date it is hoped that the Coast and Geodetic Survey can reduce the work in Porto Rico to show the isostatic situation under that island.

In addition to the studies which should be made of existing data, new fieldwork should be undertaken in those countries where such work has not been accomplished. This is especially desirable on groups of islands and isolated islands in order to throw light on the isostatic conditions in ocean areas such as the Pacific.

It is hoped that a satisfactory apparatus may be devised for determining the intensity of gravity at sea, using special vessels or commercial vessels. There are several types of apparatus in existence, but no one of them gives results of sufficient accuracy for the study of isostasy. The writer suggests that it may be possible to obtain a fair value of the intensity of gravity at sea by the use of the land apparatus properly mounted on a vessel. The apparatus would have to be swung in double gimbals and should be placed near the point of minimum translation resulting from the pitching and rolling of the vessel.

It is believed that in the study of geological structure of the Pacific, isostasy must be carefully considered and the geodetic evidence available in any particular region must be used.

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SOME FUNDAMENTAL PROBLEMS OF DIASTROPHISM AND THEIR GEOLOGICAL COROLLARIES WITH SPECIAL REFERENCE TO POLAR WANDERINGS

By Leo A. Cotton

[This paper of 103 manuscript pages is an exhaustive discussion of contemporary views of the evidence from mathematics, astronomy, geodesy, seismology, volcanism, and metamorphism as bearing on the constitution and physical properties of the earth's interior. Geological corollaries are discussed under the headings: periodic diastrophism, climatic changes, migrations of fauna and flora, possible predominance of shallow water sedimentation, permanence of continents and ocean basins, and linear distribution of orogenic and volcanic processes. It will probably be published in full elsewhere. The nature of the subject and the limitations of space permit the publication in the Proceedings of only the following Summary and Conclusion. —*Committee on Publication.*]

SUMMARY AND CONCLUSION

The subject of polar wandering has, except perhaps in Germany, almost ceased to receive the serious consideration of geologists. This is due to the supposed irreconcilable opposition of the mathematicians, particularly G. H. Darwin, whose conclusions have been widely quoted in opposition to any theory involving a large displacement of the earth's axis of rotation. A closer examination of Darwin's paper, however, shows that the limits which Darwin set upon polar wanderings were based on the assumption that only the surface rock masses were involved in the displacements; and that the earth as a whole behaved as a perfectly rigid body. On the other hand Darwin concluded that quite extensive polar wanderings may have taken place if the earth were capable of yielding like a viscous solid for stresses of secular duration. The whole question is, therefore, one which depends on the primary assumptions as to the nature and constitution of the earth's interior. For this reason a special inquiry was undertaken in order to ascertain and summarize the evidence bearing on this important question. The

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result of this inquiry showed that mathematical theory, geodetic evidence, the testimony of seismology, and geological observations all converge towards the conclusion that the earth as a whole behaves like a highly viscous solid and is capable of closely approximating to the form appropriate to hydrostatic equilibrium for forces of secular duration. This view is not, however, opposed to the conception of the earth as a highly rigid body for stresses of short periods such as those involved in the propagation of seismic waves and of tidal deformations. When these postulates are substituted in Darwin's analysis, instead of the postulate of a perfectly rigid earth, the mathematical investigation actually supports the view that polar wanderings are not only possible but probable. The acceptance of the theory of polar wanderings as a working hypothesis leads to a number of geological corollaries which are of great interest and importance.

The capacity of the earth to resist stresses up to a certain limit before deformation takes place is strictly in harmony with the history of diastrophism as read from the geological record; and provides a possible physical basis for that rhythm and periodicity which Barrell has so ably distinguished from his study of the stratigraphical record.

Climatic changes, too, would naturally attend any considerable displacement of the poles, and such changes might find, in part at least, their explanation in this hypothesis. The glacial and desert climates of the geological past, by virtue of their abundant records, should prove an interesting field of investigation from this point of view.

Again, it has long been pointed out by geologists and biologists that the hypothesis of a wandering pole would provide a convenient explanation of many difficult problems in distribution, migration and extinction of faunas and floras.

The great prevalence of shallow water sedimentation in the stratigraphical record may also find a partial explanation in the huge fourteen monthly tides which would be set up under certain types of polar displacement.

The hypothesis of polar wandering is not incompatible with the doctrine of the permanence of the continents and ocean basins, but rather supports that view.

Finally the linear disposition of folded mountains and volcanic belts may also find a simple explanation on the basis of this theory of polar wanderings. We are therefore no longer

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justified in setting this hypothesis to one side on mathematical grounds; and in view of its possible applications to many geological problems, it would seem desirable to keep it in mind in any investigation into which such a theory may enter.

If the theory of polar wanderings be merely accepted as a working hypothesis no harm can be done. On the contrary, it may stimulate investigation into many fields of research so that, even if the practical applications of the theory be ultimately shown to be quantitatively small, such investigations may bear fruit in other ways. With this reservation and hope this paper is offered to those who may be interested in this province of research.

THE "VARVE" SHALES OF AUSTRALIA

BY SIR T. EDGEWORTH DAVID, Professor of Geology and Physical Geography, University of Sydney

This paper, read at the Conference by Leo A. Cotton, has been transmitted for publication to the American Journal of Science. It describes Varve shales of middle Carboniferous age and of late Proterozoic or Lower Cambrian age from New South Wales.

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GLACIATION OF THE MOUNTAINS OF JAPAN

By N. Yamasaki

Abstract: (The complete paper has been submitted for publication to the American Journal of Science.)

Glaciation has been recorded for few places in eastern Asia. Locsy noted ancient moraines in the Province of Szechuan, China, but practically nothing is known of the glacial history of the Amur region, Siberia, and Kamchatka.

For Japan Milne demonstrated the possibility of Pleistocene glaciation on meteorological and biological grounds and undoubted field evidence has recently been obtained by Dr. Yamasaki who described well developed cirques at valley heads in the central range of the "Japanese Alps." Other cirques were found on the ridges of Yakushidake and Tateyama. Dr. Yamasaki concludes his paper as follows:

"The lofty mountains in Middle Japan in 36° North latitude were once covered by permanent snow and bore glaciers. Its existence is clearly proved only by the characteristic cirque topography with the corroborating evidence of moraines and striae. The floor of many cirques are nearly at a uniform elevation, 2550 meters, which marks the former snow line. The glaciers were hanging glaciers and not of great extent and were located near the summits of the ranges. No glacial or glaciofluviatile deposits have been discovered as yet that would allow of exact determination of the date of the glaciation. In short, the glaciated area of Japan is limited to a small district of high elevation, in great contrast to the vast extent of the glaciated areas of America and Europe. The lack of traces of glaciation in eastern Asia, even in high latitudes, will also deserve further research. How and when did the ice age occur in our country? How is it related to that of other regions? Especially necessary are actual observations and comparative study of the data. To such research, I am sure, this Conference will give the best opportunities, and I beg you, gentlemen, to kindly help me with your valuable suggestions as to the present subject."

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THE GEOLOGICAL STRUCTURE OF THE PHILIPPINES

By Warren D. Smith

The Philippine archipelago consists of a group of about 3000 islands extending from 5° 30′ to 21° 30′ north latitude and from 117° to about 127° east longitude.

Practically all of the principal geological formations are found in the islands. (See "Brief statement on Post-Cretaceous Formations in the Philippines" printed in these Proceedings). On a basement complex of igneous rock lie some small outcrops of Mesozoic rocks; and many thousand feet of Tertiary sediments succeeded in turn by andesitic lavas; great accumulations of more recent tuffs and considerable areas of foraminiferal and coral limestones. Contrary to the formerly accepted idea, the Philippine islands are not dominantly volcanic. Active vulcanism in recent years has been manifested at three rather widely separated points; at Taal (40 kilometers south of Manila), Bulasan in the extreme southeastern part of Luzon, and on Camiguin Island off the northern coast of Mindanao.

Structurally we may consider the Philippine archipelago as the crumpled edge of the Asiatic continental shelf. A study of the hydrographic chart of this region reveals a great "foredeep" close to the eastern margin of the group in which the deepest known part of the Pacific is located 85 kilometers northeast of the island of Mindanao.

To the west of the archipelago is the much lesser deep of the China Sea, presumably a sunken area or "graben." This China Sea "graben" is undoubtedly analogous to the submerged area between New Zealand and Australia, and the Asiatic mainland may bear the same relation to the Philippines as Australia does to New Zealand.

The land areas of the Philippines are merely the higher portions of a partly submerged mountain mass, in part the crests of anticlinoria, in part the upthrust blocks or "horsts" caused by faulting. Some of the straits, consequently, are the downfolded areas or synclines, while others are "grabens." The structure of the archipelago is by no means simple and besides the folding and faulting mentioned there are volcanic intrusives and extrusives which further complicate matters.

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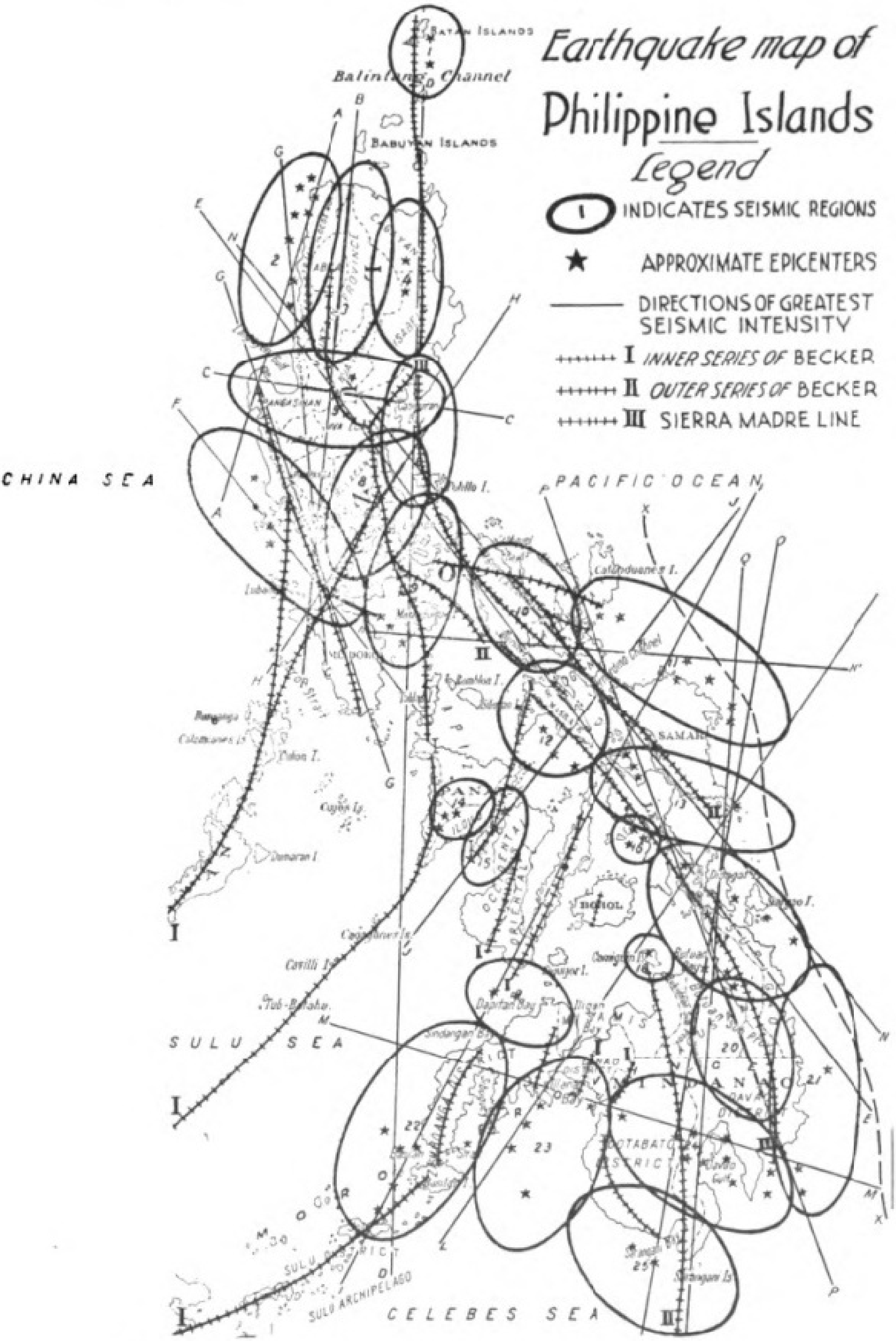


FIGURE 1. Earthquake map of the Philippine Islands.

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As for the geological dates when the major deformations occurred we can state with a fair degree of certainty that there was a period of intense deformation prior to the Tertiary when some of the schists were formed, although some schists appear very clearly to have been made as a result of strong movements in Tertiary times. At the close of the Miocene, as a part of the world-wide "Miocene revolution," the Vigo and Batan groups (middle Miocene) were generally folded. In some places intensely crumpled and faulted. Again, at the close of the Pliocene, or early in the Pleistocene, as evidenced by the Malumbang, there was another period of folding, though not so pronounced.

On figure 1 are shown the principal arcs following Becker, and the relation of these structural lines to the seismic regions of the archipelago as worked out by Maso and the writer. These arcs fall into two series, an inner one, northeast and southwest, and an outer one, northwest and southeast.

The principal northeast-southwest arcs and tectonic lines in the archipelago are as follows, beginning with the innermost, to the west:

1. The Palawan arc, which is continued into northeast Borneo;

2. The Cagayan arc, in the Sulu sea;

3. The Jolo arc, which is continued through the Zamboanga Peninsula and also passes through Cebu Island.

Taking up next the northwest-southeast lines, including several that are nearly north and south, we have, beginning at the west:

1. The Zambales line, through the extreme southwestern part of Luzon;

2. The Cordillera Central, running nearly north and south as the backbone of Luzon.

To the east of this, with a synclinal between, lies the Sierra Madre line along the east coast of Luzon. The Cordillera Central and the Sierra Madre line coalesce in the province of Nueva Ecija, in what is known as the "Central Knot." From there a single line passes to the southeast through the Tayabas Peninsula, Masbate Island, by way of the eastern prong of that island, thence through Leyte Island and down the eastern margin of Mindanao. Well to the eastward of this line, in the extreme

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eastern part of Luzon, is another line which runs more nearly east and west. This line we may call the Camarines line.

The three important points where these lines intersect are as follows:

1. In southern Luzon, near Taal volcano.

2. The northern part of Masbate, where there is located an important gold field.

3. Northwestern Leyte, where petroleum residues from ancient seeps have long been known.

4. A fourth possible junction is in the northern part of Mindanao, near Camiguin Volcano.

Whether or not there is any direct connection between these facts is not certainly known; nevertheless, such connection is strongly suggestive.

Although the principal tectonic lines in the archipelago are in general north and south, the inner line of arcs makes a pronounced curve in the direction of Borneo, showing a tendency to fall in line with the principal tectonic lines of the rest of Malaya which have in great part an east and west direction. It may be questioned as to how much emphasis we are to put on the word "arc." These may be a series of broken straight lines and not strictly accurate. It is seen, therefore, that the Philippines are part of a region, including also Java, Borneo, and Sumatra, which, with reference to Asia and Australia occupies a position analogous to that of Central America and the rest of the Americas and therefore is a region of strategic importance in the study of the geology of the Pacific. Previous to the Miocene there was undoubtedly sea connection with Europe by way of a greatly extended Tethys which reached from the Pacific to the Atlantic.

Becker, Koto, and others have pointed out the relation of the Philippine arcs to those of Asia as delineated by Richthofen.

As has been pointed out by Suess, and similar to what Omori has told us of Japan, and Andrews of Australia, the outer arc is one of closely folded rocks, and within this outer arc is a line of volcanoes such as Taal, Canlaon and Camiguin. However, near the outer arc are two important cones, Bulasan and Mayon, that are active at intervals. The innermost arc consists of folded rocks also, but with no sign of volcanism, at least at the present time. As in the Australian region, the outer arc is the oil arc.

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On the western side of the archipelago there is much evidence of recent uplift, especially indicated by raised beaches and reefs, while on parts of the eastern coast, especially in the Paracale region, drowned river valleys are found. In the eastern half of the group, too, though not on the eastern coast, there are two great rivers, the Cagayan in northeastern Luzon and the Agusan in northeastern Mindanao, up which the tide runs for long distances. It seems to the writer that in spite of some local exceptions to this state of things, there has been a tilting of the Philippine block toward the Pacific, perhaps a down drag as a result of the subsidence of the oceanic block into the Mindanao deep. Certainly this has not been a uniform tilting as the facts would indicate a warping.

The archipelago, as a whole, has been subjected to a great uplift during the Pleistocene and Recent periods amounting to some 1,800 meters (6,000 feet). This is evidenced by the fact that fossil plants, very closely related to the flora of the lowlands near Manila, have been discovered in the extreme highlands of Luzon.

Residual plateaus in parts of the islands, notably around Baguio in northern Luzon, and even skylines in the uplands of Cebu, of what might be taken as evidence of peneplanation, but these areas may have had totally different origins and may perhaps be explained in an entirely different way.

Of two things we may be certain; namely, the structure of the Philippines is very complicated, and we lack sufficient detailed surveys to enable us to pronounce finally on many of these points.

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SYMPOSIUM ON MEANS AND METHODS OF COOPERATION

(From the stenographic record of the General Session, August 19, 1920)

REMARKS BY MR. RICHARDS

We have discussed the nature and urgency of the problems which form a proper basis for the investigation of the Pacific. It is desirable, however, that there should be some definite plan, properly organized on a permanent basis to insure the proper handling of these very important problems. Associated with this plan should be all the scientific institutions, museums, universities, and the governments of the several Pacific countries. We have representatives from Canada, the United States mainland, the Philippines, Hawaii, Australia, New Zealand, Japan, and China. It seems desirable that the delegates from these countries present at this Conference should leave with Professor Gregory a list of those organizations which, as far as their particular countries are concerned, should be associated with this scheme. We have no representatives from the British, French and Dutch possessions within the Pacific, although invitations were sent to them. Their coöperation should in some way be secured.

In order to get ahead as rapidly as possible we should consider the constitution, which a permanent organization such as I have briefly outlined, should have, and, it seems to me that the constitution of this Conference might serve as an excellent base upon which to build a permanent one. It would be necessary, however, to select representatives of these governments and institutions so that there would be some definite channel of communication.

It might be advisable to decide upon the next meeting-place of this Conference and the period of time which should elapse between this meeting and the succeeding one. Various places have been suggested: Tokyo, San Francisco, Suva, Noumea, Sydney, Wellington, and Manila. It is not only the duty of all the governments and scientific institutions of the Pacific to deal with these problems of the Pacific, but it is also their privilege, and it is the duty of those of us who are present

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here to point out to our respective countries that it is their privilege to contribute funds toward the carrying out of these particular investigations. Some governmental bodies and private institutions are in a better position than others to contribute funds, but a common pooling of the funds should be made. Funds are necessary for the sustenance, travel, and necessary equipment of the various research workers selected to tackle these problems. I take it that these research workers will be selected by some permanent council appointed by this organization, and definite funds set aside for the particular investigations. When the work is completed, funds should be available for publication and distribution of the results of the investigations. Funds are necessary, also, for carrying out the future meetings of the permanent body, such as we hope to see set up.

There are several institutions in Australia which those of us who come from there can get in touch with. There are the Commonwealth Government, and the several state governments—the states on the eastern side of Australia are particularly concerned. There are the universities in each of these states; the various Royal societies, one in each state, and another strong organization, the Linnean Society, in New South Wales. We have an embryo institution of science and industry, which will be administered by the Commonwealth. There are also the several museums. Thus there are quite a number of bodies within the Commonwealth of Australia whose duty and privilege it is to join in these investigations.

We should then have a definite organization, properly constituted and set up on a permanent basis; an organization which should be thoroughly representative of the governments around the Pacific and within the Pacific. To get the full coöperation, the proper good will, and hearty support of all these, it will be necessary to approach the administrative heads of the various possessions in a proper fashion. As a means to this end, the delegates should place before their respective governments and institutions the purpose and scope of this Conference. With representatives in the different places, we have machinery to carry on, to fix upon the necessary center, and the time that the next conference can meet. I feel that we have done a great deal, and have made a definite step toward making a sound organization.

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REMARKS BY MR. EVERMANN

I can speak officially only for the California Academy of Sciences. Various other scientific bodies and organizations in California are more or less interested in this question of the Pacific. California has a peculiarly favorable situation as regards the Pacific Ocean problems. People from eastern United States pass through California, and most of them go through San Francisco when going to or from the Pacific. Those of you who are in the Pacific, west or southwest, when you come to America come through Honolulu to San Francisco, and that makes California a peculiarly interesting place in relation to these questions of the Pacific. Now, as to just what the means, methods and ways of coöperation among the various institutions may be, it seems to me that this will be a matter of gradual development. There are in California, besides the California Academy of Sciences, some four or five other scientific organizations that are interested in these matters. There are Stanford University with its seaside laboratory, the University of California, the California Fish and Game Commission, and the Scripps Institution for Biological Research, all of which are deeply interested and most of them actively engaged in work connected with the exploration of the Pacific.

Speaking for the California Academy of Sciences, I can assure you that the Board of Trustees, the Council, and the Museum staff are willing, anxious and ready to lend any assistance that they can in furthering the aims of this Conference. Some ways in which it seems possible to be of service are as follows:

Scientists passing through San Francisco may find the Academy of service as a sort of way-station to which they may have their mail addressed, their express packages sent for holding until they arrive or until they are ready to depart for the work on which they are engaged. We shall be glad to allow the Museum to be used as a resting place for every person who comes. The libraries and collections of the various departments may prove of particular value, especially those of botany, herpetology, conchology, and ornithology. In the department of botany is to be found a fine collection of exotic species that have been introduced into California, many of these being found in Golden Gate Park. In the department of conchology the major portion of the Hemphill collection of shells is to be found.

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The entire collection of the department of herpetology was destroyed in 1906, but it has since been built up so that it is now the third largest in America, surpassed only by collections in the museum at Cambridge and in the National Museum at Washington. The libraries of the California Academy of Sciences, of the University of California and of Stanford University would be at the disposal of anyone who wished to consult them, and the aggregate of those three libraries is quite considerable.

There is, perhaps, no place in America where the fishes of the Pacific could better be studied than at Stanford University. It contains the largest collection of fishes outside of the National Museum. Those who wish to examine specimens of fishes of the Pacific will be welcome, and the ichthyological library of that institution is perhaps the best in America.

The California Fish and Game Commission is another institution ready to coöperate in solving Pacific problems. It is engaged in studying economic problems in regard to fisheries and has a vessel, the *Albacore*, which is adequate for trips along the Pacific and out 100 miles. The present attitude of the Fish and Game Commission is very cordial toward scientific work. That body would be of very great assistance to anyone interested in studying problems along the California coast. Then there are the stations at Pacific Grove and the laboratory at La Jolla, for which Dr. McEwen can speak more particularly.

The California Academy of Sciences hopes to have the Steinhart Aquarium in operation within the next eighteen months. We expect to put about $270,000 into the building and its equipment; and there is a fair prospect that we shall be able to secure a like sum for the equipment and maintenance of a biological laboratory in connection with the aquarium. The aquarium will be located in Golden Gate Park adjoining the Museum. It will be both a salt-water and a fresh-water aquarium, and will be equipped to maintain fishes requiring any temperature. We hope to make a special feature of Hawaiian and other tropical fishes and invertebrates. We hope that the aquarium may be found useful to biologists who wish to carry on studies of living forms of aquatic life, whether of fresh or salt water.

Summing up, then, I wish to say that the resources and the facilities of the California Academy of Sciences are at the dis-

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posal of the members of the Conference and of individuals working with them.

REMARKS BY MR. THOMSON

In a very interesting paper recently issued by the National Research Council of America, Mr. Elihu Root pointed out that science had taught the world how to organize but had not yet organized itself. Can science organize? Can you assign definite tasks to scientific men and get the best results from them? The answer must be no. The greatest advances in science have been made by men of genius. If we had men like Faraday or Darwin in the Pacific they would not be guided by the program of this Congress. They would pick out facts here and there and start some illuminating hypothesis that would render a fresh program necessary. I do not mean to say by this that program work is not possible. We have only to look at the work done by geological surveys working according to programs to see that it is possible to get somewhere. We are not all men of genius, but I simply wish to sound the warning that we must give a free hand to men who wish to work not according to program.

I wish to call attention to three types of coöperation: (1) government and organized bureaus; (2) institutions; and (3) individuals. It is perhaps fitting that I should say something about the work of governments as I am a representative of the Government of New Zealand, and I think the only direct representative of a government here. There is a great difference between colonial governments and those of the United States and Japan. We find that in science, at least, a prophet has no honor in his own country. We put programs before our governments, but rarely are they carried into effect. I do not know whether your governments are the same as ours, but we find it sometimes very hard, although we can make out a very good case, to get the Government to act, and for that reason we always welcome any external pressure. For instance if any suggestion comes from official circles in London it is acted upon at once, whereas we may have been advocating the same thing for years without the least response. But I gather that this Conference does not wish to dictate to governments what they should do in carrying out the scientific exploration of the Pacific. In New Zealand you can get around that difficulty in one way, viz: if you do not like to pass any resolutions

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telling governments what to do, at any rate you can make clear to the New Zealand Institute what it ought to do or what it ought to get the Government to do.

Now I think it is a fair thing to expect that the various governments in the Pacific should do a great deal to carry out the program we have laid down for the charting and geological surveying. It is fair to expect the New Zealand Government to take care of this work in Samoa and the Cook Islands, Australia that in New Guinea, Britain in Fiji and Tonga, France in New Caledonia, New Hebrides, Tahiti, and so on.

I think the most practical way to get New Zealand properly interested in this work of the Pacific is to hold a conference like this in New Zealand. Then without appearing to dictate you can persuade the New Zealand Government to coöperate with us. I should be very sorry if this Pan-Pacific Scientific Congress was held always in Honolulu. If you will send a strong delegation from America, Japan and Australia to New Zealand you will take the very greatest step you can to insure the desired coöperation so far as New Zealand is concerned. I might mention here that we held a meeting of the Australian Association in 1904 in New Zealand and it was directly due to that conference that the geological survey was reorganized, and the work of describing the fossils taken in hand. Now we have in 1923 a meeting of the Australian Association in New Zealand. You can depend upon it there will be one or two hundred Australians at the meeting. Would it not be the time and place to fix upon for the next meeting of the Pan-Pacific Scientific Conference? Other meetings in Canada, the United States, Mexico, the South American republics, Australia, the Dutch Indies, Japan, Fiji, and Tahiti would in course of time bring the scientific problems before all the peoples of the Pacific.

Turning now to institutions I would like to speak of the New Zealand Institute. This is a federated society which represents the whole of the scientific men in New Zealand and you can rely upon coöperation from that body in every possible way. We have also the Polynesian Society. This society, it is only fair to say, has done as much for Polynesian research, although it is only a small body with small means, as nearly all of the rest of the world put together. This is due mostly to Percy Smith, President of the Society, who would have been here were he not too old to travel. So long as the Polynesian

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Society is under Percy Smith and I think after Percy Smith goes, you can rely upon the utmost coöperation and help from that body. But, indeed, I am not sure that the coöperation should not be the other way. If this Conference could put that society on its feet financially it would be doing a great work. Its finances do not permit it to publish all the valuable material it has accumulated. It has members all over the world and perhaps some of the members of this Conference would like to join it. It is now exclusively a New Zealand society.

I was discussing the question of Pacific research with Mr. R. Speight, Curator of the Canterbury Museum. He has a strong feeling that what we should do in New Zealand is to take the outlying islands of New Zealand first and work all these so far as possible. An enormous amount of work waits to be done in this way in the Chatham, Auckland, Campbell, Bounty, Snares and other islands.

The universities in New Zealand are somewhat different from American institutions. They are both college and graduate schools in one. There is a very encouraging sign in regard to Pacific study in that geography has at last been elevated to a position among the sciences, and modern geography as opposed to commercial geography is now being taught in at least one college. We now have also a place in our University curriculum for anthropology, and one college is teaching it, but we have no graduate students as yet. In a few years we may hope to have graduates taking their place in the work of the Pacific.

With regard to coöperation among individuals, its two main means would appear to be (1) through correspondence and exchange of publications, and (2) through travel and meetings. Of course we are not all good correspondents, but at least we can send our publications freely around the Pacific. It is wonderful how publication will stimulate the mind and set it working. I for one haven't time to dig into magazines for scientific articles except on the line of my immediate work, but when a pamphlet is sent me I always read it, and enjoy it.

I think there is nothing which will lead to greater coöperation in the work of the Pacific than travel. In recent years to mention only geologists we have had Professor Davis, Professor Iddings, Dr. Gregory and Dr. Jaggar, in New Zealand. They have done a tremendous lot to widen our horizons and I hope that this kind of individual travel will go on.

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REMARKS BY MR. FRASER

We in British Columbia are very much interested in coöperation because it has been necessary to have a great deal of coöperation in order to accomplish anything. Canada is a large country but from the Rocky Mountains eastward the interest in the Atlantic is greater than in the Pacific. Any institution in British Columbia, therefore, has to look to other British Columbia institutions for assistance. These institutions are as yet very young and have need of assistance and the coöperation of individuals and institutions elsewhere. The Biological Station has been in operation for only twelve years, and the number of workers at all times has been small. So far as the University of British Columbia is concerned, it is but five years old and has not yet had a chance to do graduate work in zoölogical research. As time goes on there is every probability that it will be closely allied with work of the marine station. The Department of Botany has been coöperating in marine work and will continue to do so. As the University gets a little older its officers and students will do a great deal of the work along the coast. Hitherto we have had to depend a great deal upon interested persons living along the coast, and have been helped by them in many ways.

I shall briefly outline some of the features of coöperation. In the first place, take the science of navigation, which dates back a long time. The people of Hawaii made it very definite that the last work of Cook's career should be done in their islands. Captain Cook at one time was familiar with Vancouver Island and following after him were Vancouver and other early navigators who were interested in geography and coast work. Surveyor J. K. Lord, who was in charge of the work of surveying and marking the boundary between British Columbia and neighboring states, published a work, "A Naturalist in British Columbia," which is almost a classic of its kind, based on specimens and data of every imaginable kind which he obtained while engaged on this work. Much zoölogical work was done by the Geological Survey under Dawson and others. Later a great deal of marine material was collected on the coast of Vancouver Island by Prof. John Macoun, naturalist of this survey. The work done by the Meteorological Service has been of benefit and this is being continued at present.

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Dr. Shipart is arranging for valuable work in regard to currents and temperature on the coast. He expects to get reports by wireless from the trans-Pacific steamers which cross from Vancouver to the Orient. Thermometers to record varying temperatures will be installed as soon as possible on the various boats. Tidal survey work is another field which could be utilized more than it has been in charting the various channels, currents and tides. Dr. Dawson is always willing to give any assistance in geographical work. The Hydrographic Survey has been doing good work in sounding and charting, but other data could readily be obtained while the work is going on. The Federal Department of Fisheries, naturally, is very much interested in the biological phase of this work, and the Provincial Department has encouraged investigation in fishery problems. The Museums at Victoria and Ottawa have helped.

As to literature we are poorly provided. At the Station we have at least 1000 volumes but that does not go far to supply the demand. At present there is a project afoot among all the libraries in Canada that carry periodical and scientific publications, whereby we are arranging to get a complete catalogue of all of that class of literature from each of the libraries of Canada.

Apart from the direct work of the Canadian institutions, we have a good deal to be thankful for in the assistance we have received from other institutions, particularly from several in the United States. We have no hesitation in calling upon such institutions as the National Museum for assistance. It seems to give them so much pleasure that we call upon them very often, and we are ready to coöperate when we are able to do so. A number of the universities in Canada and the United States, however distant from the seaboard, would be interested in Pacific work if the situation could be placed before them. Museums and universities in the eastern part of Canada such as Toronto and McGill, have done good work. It is quite possible that many more of the eastern institutions could be drawn into the work if we only told them about it. Out of this Conference should develop an understanding that any institution in any country may be appealed to for assistance as far as its resources will permit.

The relations of various biological stations on the Pacific coast are good. Puget Sound station, which is only 70 miles

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from the station at Nanaimo, and the Minneapolis station near by, coöperate with us and there is no particular reason why that coöperation should not be extended. Now, when we go back to our institutions, we should feel more keenly the necessity of coöperating, of increasing the dissemination of literature, and of traveling from place to place to get a broader view. Many institutions are getting too much inbred. The sooner a change is made in that regard, the better.

REMARKS BY MR. HENDERSON

I need hardly assure the members of this Conference that the United States National Museum aims fully to coöperate with the workers in the Pacific. We are limited in some ways, but in others we can help. Our funds for exploration work are not very great but in some way or other we can usually count upon outside assistance. A great deal of our work has been carried on in that way; so that if you want any particular island investigated, call upon us and we will see what we can do.

The National Museum is the depository of an enormous collection of scientific material. For many years it has poured in in a steady stream. The care and preservation of this material has been the chief object of the Museum. Much of this material has been reported upon but too much of it has not. I think perhaps you might help us if you could take some action calling upon us to overhaul the Pacific material in the Museum. We might use such a resolution to aid us in getting money for the purpose from Congress. Owing to the great amount of material collected, our staff at the Museum seems very small. Therefore I think we can avail ourselves of such a resolution to enable us to get our collection of Pacific material listed and published.

Let me enumerate some of the ways in which we can coöperate with you:

1. We can do a great deal towards identifying material sent to us.

2. We can welcome any student you send to us, entirely surround him with specimens, and give him the use of one of the best libraries in the world.

3. We are willing to send material to any accredited workers in the Pacific to aid them in completing their work.

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Whenever a man starts out anywhere to work up a group of animals or plants or any particular fauna or flora, he needs all the available material in the world bearing upon his subject. He does only 60 per cent or 70 per cent work if he hasn't it at his command. We need 100 per cent work these days, and therefore I think that wherever the need exists all museums should go to the rescue. We only ask that the call be approved by some museum or other recognized institution of scientific research. We might even send out actual types. I believe that if we have any types in our collections from Australia, or Japan, it is for the general best interests to send them to those countries. On the other hand I think that if museums in those countries possess types of American species, they should give them to us. I feel strongly in this matter because if the types of a fauna a man is studying are scattered all over the world, if he has to go to France for this, to England, to New Zealand or the United States for that, it takes all of his time and more than all his money. It is better to have the types of Europe in European museums, of the Americas in American institutions, and of Australasia in Australia and New Zealand. In regions where there are no proper facilities for preserving such valuable objects, they should be kept in the centers of scientific activity most nearly concerned with their study. I appreciate the difficulty of accomplishing this as I understand the unwillingness of curators to part with such important elements of the collections in their charge. But such a yielding on their part to the greater good will eventually come.

I have nothing more to say except to assure you that the National Museum will do all it can to carry out your suggestions.

REMARKS BY MR. KISHINOUYE

Scientific coöperation is, we believe, more necessary in Japan than in any other part of the world. We are separated from the centers of scientific activities, and often lack type specimens and the newest literature. We feel keenly some drawbacks in carrying on scientific investigations in the Orient, though the Japanese islands extend a great distance from north to south and are rich in flora and fauna. At present we are carrying out investigations and keeping in correspondence with colleges and institutions in foreign lands.

Taking an example in my own line of study, I found that the tunny *(Thunnus Orientalis)* of my country is a little dif-

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ferent from the European species and I was very anxious to get specimens of these for comparison. Before the great war I wrote to the Zoological Station at Naples asking it to send specimens of European tunnies. They sent the specimens on board a German steamer just prior to the outbreak of the war but unfortunately the steamer was confiscated in the Red Sea and so the specimens never reached me. Often we have such inconveniences. We wish therefore, very ardently the cooperation and exchange of publications and specimens in my country. But many of these publications are written in Japanese, and although we send these publications to you, you can not understand them, though perhaps you could get some ideas from the illustrations.

In our old literature written in the time of our grandfathers or great-grandfathers, we find sometimes valuable information which often gives hints in making new investigations. This literature is mostly unknown in Europe and America. We believe we can give assistance in making this literature available and also in extending to you the privilege of studying in our biological stations. In that way we can return your kindness in sending valuable specimens and publications to our institutions and investigators.

REMARKS BY MR. McEWEN

The work of the Scripps Institution originated about 25 years ago in the desire of a few zoölogists from the University of California to learn something of the practically unknown animal life in the Pacific or to extend their efforts to marine biology.

My own work has not been biology but rather an attempt to coöperate with biologists in the effort to learn of the distribution of marine life and the relation of these organisms to their environment; so that the leading idea of the institution is a program of work carried out, perhaps, as in a factory system where each individual has a certain duty to perform in attaining the general object. Each one would have at least some comprehension of the needs of the others and of the work they were doing.

In order to do this work a salary was necessary to insure continuity of effort. Also with our rather limited funds it was necessary to restrict the work to a small area. And so our work

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has been almost entirely local and as continuous as possible both in time and space within this locality.

The result of these efforts has led also to another feature of our work, namely, that of the development of methods of dealing with results thus obtained. It is fully recognized that such intensive work must be quantitative. The determination of the laws of relationships is a matter of exact reasoning and consequently a good deal of attention was given to the mathematical application particularly to the statistical study in the field of biology, and to the study of the physics and mechanics of the ocean. The facts with reference to the oceanographical work can to a certain extent be directly observed, and to a certain extent require the careful quantitative study of the data, in the same manner as a problem in the laboratory, with a view to determining these things that can not be observed directly.

While we have this definite program of work which we are doing, we also have facilities for visiting scientists who are welcome to the use of the laboratory and the library for their own individual problems, and we nearly always have visiting scientists of that type.

The members of the scientific staff believe that the idea of coöperative effort directed toward definite ends, but allowing for individual freedom and initiative, as has been tried out within the Institution, should be given due attention in the larger undertakings concerning the Pacific as a whole.

I may perhaps conclude with an excerpt from an outline by Professor William E. Ritter, Director of the Scripps Institution, on "The Role of the Scripps Institution in a Program of Pacific Exploration:"

REQUISITES FROM THE STANDPOINT OF THE SCRIPPS INSTITUTION FOR THE "EXPLORATION OF THE PACIFIC AREA"

1. Extension of coöperation among marine laboratories of the area.

2. Additional funds for shore-laboratory investigation and boat work.

3. Utilization of merchant ships for field collecting.

4. Better coöperation with fisheries.

5. Coöperation with surveys, etc., for marine cables.

6. Government participation: Bureau of Fisheries; Coast and Geodetic Survey; Lightships and Lighthouse Service; Weather Bureau; Navy.

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COMMUNICATION FROM PROFESSOR DALY

Reginald A. Daly, Professor of Geology, Harvard University, in a communication submitted to the Committee on Program (published also in American Journal of Science, Vol. 41, 1916): While individual investigations have been stressed in the present note, the writer shares in the main concern of the Conference. It has been called primarily to illustrate and further the spirit of cooperation. The only economic way of reaching the truth of nature is to cooperate, first, last, and all the time. A body of specialists, *together* questioning *all* of the Pacific oceanic islands, are sure to reach final results quicker than is possible to a much greater number of equally capable men who independently "monograph" islands or island groups. Regarding the origin and distribution of organisms or rocks, the testimony of a single island or group is bound to be doubtful. The very refinement of analysis in a restricted area may give misleading results and represent energy worse than wasted. A problem vital to the biology or geology of a single island or group may be supremely difficult, or impossible, of solution, if attacked merely in the light of local facts; yet the solution may soon be clear as day when information comes from neighboring islands or archipelagoes. Negatively, in the prevention of waste of energy, as well as positively, in the conscious adoption of the only feasible method of reaching final truths, the plan of comprehensive, synthetic exploration of the Pacific islands has claims for serious consideration.

REMARKS BY MR. PILSBRY

As the general aspects of this question at issue have been gone into somewhat fully, I will make my remarks very brief.

The Academy of Natural Sciences of Philadelphia has been more or less interested in Pacific problems almost from its beginning. A paper published nearly 100 years ago dealt with Pacific problems. In the last few years it has published several volumes dealing exclusively with Pacific island fauna and flora and also extensive papers on Pacific fishes. Part of this work was done in collaboration with the staff of the Bishop Museum. Specimens from other museums of the United States and England were used so that there has been a certain amount of coöperation between museums in this work of Pacific exploration.

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There will necessarily be a good deal of subdivision. Certain institutions will be able to take up groups either geographic or biologic. It is a question now whether parceling out the work between the various institutions is not one of the first things to be done.

However, the financial question is at the root of this matter. It seems to me that it may be possible for several museums or other institutions to coöperate in sending an investigator and share in the result as well as in working up the material which would be secured. I am sure that the Academy of Natural Sciences will be willing to continue to collaborate in Pacific work to the extent of its ability as it has been doing in the last few years.

REMARKS BY MR. CUSHMAN

The Boston Society of Natural History at Boston and the Museum of Comparative Zoölogy at Cambridge are coöperating so that Pacific-type material is being concentrated at Cambridge. The Pacific foraminifera studied by me is being placed in the United States National Museum where it will be available for future workers in the group.

REMARKS BY MR. MERRILL

I will confine my remarks to two subjects: (1) the relationship of the Philippine Bureau of Science to the topic under discussion; and (2) certain details of coöperation that have been developed in the Philippines.

In reference to coöperation between the Bureau of Science and other institutions, it should be definitely understood that the Bureau is entirely supported by government revenues and its expenditures are limited by the Legislature. This is also true of other institutions in the Philippines which are in a position to coöperate; there are no privately endowed institutions.

The Bureau of Science, which I represent officially, is an institution of very comprehensive scope. While we do a considerable amount of scientific work as such, we are compelled from the very nature of the institution to do a great deal of practical work and much of the activity of the Bureau involves the application of science to economic problems. Coöperation is of course limited by the technical personnel available which varies from year to year; but so far as possible it is the definite policy of the institution to coöperate to the greatest possible extent not

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only with other government units in the Philippines, but with scientific institutions in all other countries. Of necessity we have had to depend to a large degree on America to supply the technical personnel of the institution. In a very high percentage of cases individuals have come to the Bureau of Science for two years or at the most three years and have then returned to the United States. Few of those who have been in the service of the Bureau of Science during the past 20 years have remained for any appreciable time. You will, of course, realize immediately that those individuals who have remained continuously are generally the individuals who have accomplished results, especially in Natural History. A man must remain constantly in his selected field for a long period of years in order to accomplish much of lasting importance. While all of the employees in the higher positions are in the civil service, yet owing to unsettled governmental policy and the continual agitation for independence, it is often difficult to induce highly trained men to remain in the service largely because of uncertainty as to the future.

The other subject I wish to mention is the result obtained by coöperation in collecting botanical material. Commencing in 1902 I have built up in a vacant room a Herbarium of the Bureau of Science of over 200,000 specimens not by purchase but almost wholly by collection and exchange of material. It is now one of the three largest collections in Asia. The success in building up the collection has been largely due to coöperative measures adopted. The serious attempt to make the herbarium an index not only to the systematic aspects of Philippine botany but to economic study as well has been so successful that the Herbarium is consulted not only by systematists but also by those interested in economic botany, agriculture, ethno-botany, philology, and other subjects. These results have been obtained by employing a simple field label on which data are very easily recorded. From the Bureau of Forestry alone collections have been received from over two hundred individuals during the last '18 years, aggregating about 30,000 specimens. Many of these are from men untrained in botany. My most efficient collector is a Filipino who never got beyond the primary grades. Abundant duplicate material has been secured which has been of the very greatest value for exchange purposes.

In securing the material now incorporated in the herbarium of the Bureau of Science the services of teachers, missionaries,

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amateur botanists, horticulturists, foresters, rangers, and others have been enlisted. When non-botanical expeditions were sent out the policy was generally adopted of supplying some member of the party with a small compact outfit for preparing botanical specimens. Thus much exceedingly valuable material has been secured often at little or no direct expense.

In the exploration of the Pacific I believe that coöperation should be developed between the different sciences. Thus, for example, most valuable botanical material could be secured from purely anthropological or geological expeditions. It is not always necessary to send a special man along to make botanical collections. Each party sent out should take a compact botanical outfit, field labels for recording notes, and should be asked to secure as much botanical material as possible without, however, infringing on the particular object of each expedition.

REMARKS BY MR. HOVEY

I am very glad to have this opportunity of saying something regarding the institution which I have the honor to represent, especially since the gentlemen who have preceded me this morning have, with one exception I believe, spoken for government institutions. The American Museum of Natural History is not, as has sometimes been inferred from its title, a federal or even a state affair, but it is supported entirely by the City of New York and by private individuals who are interested in the purposes for which it exists and the work which it is doing. It may interest those who are not familiar with the administrative side of the American museum to know that there is direct coöperation between the city and her citizens in carrying on an enterprise of this character, whereby the city owns the building and the land whereon it stands and provides an annual appropriation towards its maintenance, while the collections, in whatever manner they may have been secured, are held in the name of a board of trustees. The latter must provide the funds for all expeditions, for preparatory and research work done upon collections, and for all publications. The funds are derived from endowment, membership fees, and general and special subscriptions. The appropriation from the city for the current year is $300,000 and the income from other sources is about $500,000.

Although the American Museum is situated on the Atlantic coast, its activities in the Pacific region have been long-con-

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tinued and extensive. Without trying to be exhaustive, I may mention the work of our Museum vertebrate paleontologists in California and British Columbia; of our mammalogists on the whales and sea elephants of the Pacific, the seals of Alaska and the land mammals of Korea, China, and Mongolia; of our ornithologists on the birds of the coast of Chile and the Andes; of our invertebrate zoölogists on the land snails of the South Sea islands; and of our anthropologists along the whole Pacific coast of North America, on the Aleutian Islands, in Siberia, China, the Philippines and among the islands of the South Seas.

I have already mentioned at another session the broad plans, amply financed, now being put into effect under the direction of Dr. F. M. Chapman, for an intensive study of the birds of the Pacific during a period of five years, using among others such noted collectors as R. H. Beck and R. C. Murphy. Dr. Chapman is likewise pushing forward the ornithological work in the Andes. Dr. H. E. Crampton is on his fifth zoölogical expedition in Polynesia. Mr. R. C. Andrews is organizing a comprehensive study of the mammals of eastern Asia to cover a period of at least five years. Dr. Wissler has told you of our plans in anthropology in coöperation with the Bishop Museum of Honolulu, one feature of which is the loan of our Mr. Sullivan to that Museum for two years of intensive work on the aborigines of the Hawaiian and other islands.

Coöperation has always been a characteristic of the policy of the American Museum, not only in field work as evidenced by expeditions in association with the Smithsonian Institution, the University of California, the Bishop Museum and other organizations, but also in the matter of gift, exchange and loan of specimens, and hospitality to research workers and preparators in our own laboratories and halls. We send our publications all over the world and we have deposited complete sets of them in several scientific centers about the Pacific, where they are available to students. Doubtless additional depositories would be established if there were need for them. We lend books from our extensive library to workers everywhere within reach in the effort to advance science.

The keynote of this first Pan-Pacific Scientific Conference is "getting together," in coöperation in exploration, collecting, research, and publication. The American Museum of Natural History desires to give to the extent of its ability in furthering this purpose as well as to receive.

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REMARKS BY MR. SAFFORD

I am sorry that the United States Department of Agriculture is so inadequately represented at this Conference. Among those connected with the Department who were invited to attend but were unable to do so were Dr. Charles F. Marvin, Chief of the Weather Bureau; Dr. Karl F. Kellerman, Assistant Chief of the Bureau of Plant Industry; Dr. Walter T. Swingle, Physiologist in charge of Crop Physiology and Breeding Investigations; Dr. David Fairchild, Agricultural Explorer in charge of Foreign Seed and Plant Introduction; Dr. C. L. Marlatt, Assistant Chief of the Bureau of Entomology, in charge of Tropical Fruit Insect Investigations; and Dr. E. W. Nelson, Chief of the Bureau of Biological Survey.

The scientific institutions of Hawaii already feel sure of all possible aid and coöperation on the part of the various divisions and offices of the United States Department of Agriculture in all their investigations and projects. It might be of interest to other delegates to know that the Weather Service is included in the Department of Agriculture, and that to this Service the Volcano Observatory at Kilauea now belongs. Other observation stations engaged in collecting and distributing climatological data are situated at Honolulu, Alaska, Washington, Oregon, California, and on the island of Guam.

Our Bureau of Animal Industry offers coöperation through its various offices and divisions, including those which concern themselves in the breeding and improvement of domestic animals, in studying the causes and cures of epidemics and infectious diseases, and in the investigation of diseases caused by animal parasites.

Our Forest Service has concerned itself with the forests of Hawaii as well as those of the Pacific slope of North America. Among other activities, our Bureau of Plant Industry deals with the propagation and breeding of plants, with the diseases of plants, with investigations of plants yielding textile fibers, with improvement of corn and other food staples, and with the introduction of foreign seeds and plants into localities suitable for their cultivation.

The office of Systematic and Economic Botany lends hearty coöperation to collectors of plants, horticulturalists, and agriculturists, in identifying plants, tracing the source of plant products, such as textile fibers, bark cloth, twine, gums, resins,

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copals, perfumes, oils, dyes, starches, stimulants, and medicines. Material of this kind together with the mother plants from which the various products were derived included in the Economic Herbarium of the United States Department of Agriculture has been received from Chile, Peru, Ecuador, Colombia, Panama, Costa Rica, Nicaragua, Salvador, Guatemala, and the Pacific coast of Mexico, as well as from the island of Guam, from American Samoa, and from the Philippines. In this connection I would call attention to all those interested in the history of exploration of the Pacific that the plants of the Wilkes Exploring Expedition are included in the National Herbarium.

In conclusion I would call attention to the activities of the Bureau of Biological Survey, which has established a bird reservation on Bird Island, an islet of the Hawaiian group, of which Mr. Gerrit P. Wilder of the Bishop Museum has been named warden. Among the results of the work of this bureau is a beautifully illustrated work on the vegetation of Lower California. Another publication which has proved useful throughout the tropical Pacific is "The Useful Plants of Guam," which contains not only descriptions of plants widely spread throughout the tropics, but also deals with the distribution of plants, the natural history of the island of Guam, and an account of the aboriginal and the modern inhabitants of the island.

REMARKS BY MR. MOORE

The Bureau of Fisheries was fortunate in having as its founder a man of very broad views who appreciated in the beginning the value of coöperation. The very first work carried on by the Bureau was coöperative work on the coast of New England and the policy which was adopted at that time has always been continued. We, therefore, feel that we are quite familiar with the methods of coöperation and as we have coöperated with all the leading biologists in the United States it is not necessary to say very much in that respect. Our physical facilities for coöperation in the exploration of the Pacific are, at present, limtied to the steamer *Albatross* with such assistance as could be rendered by our fish culture stations in the Pacific coast states.

I believe it is not necessary to say very much in regard to the *Albatross* which has carried on very extensive investigations in tropical and north Pacific waters. She has been the medium for a number of expeditions which have explored the islands of

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the South Seas, Japan and the vicinity of Hawaii and the Philippines, and the publications on the subject of these cruises are quite extensive. Some of them are invaluable in the marine biology of the Pacific.

I wish to say that the policy which the Bureau of Fisheries has followed in the past will be maintained and that if coöperation is desired all that is necessary to secure it is to ask for it. All reasonable requests will be met, and on the other hand the Bureau of Fisheries will call on other scientific institutions for aid if it cannot accomplish what is desired through its own efforts, and shall expect it to be granted if reasonable and proper; but if it be refused, no resentment will be felt. In other words, we understand that coöperation is an arrangement which must be mutually satisfactory.

Now in regard to the general subject of coöperation, particularly in respect to the policy of this meeting: after the close of the war between the Northern and Southern States of the United States, the country found itself on a paper money basis and there was a great deal of discussion about how specie payments should be resumed. That discussion continued until John Sherman said that the way to resume was to resume. And that is how I feel about coöperation—the way to coöperate is to coöperate. I do not feel that a discussion of the general methods is of a great deal of value. If we possess the spirit of coöperation we will put that spirit into actual operation, into actual effect.

I believe that this congress will not accomplish very much unless each of us, when he leaves here, goes with the idea of putting himself individually, in his own person or as the representative of an institution, back of the things we have been discussing. The successful prosecution of the work we have discussed here depends on how soon we are going to "get down to brass tacks," get together and draw up specific plans based on the general broad plans we have discussed here and find ways and means of putting them into execution.

REMARKS BY MR. GREGORY

Discussions during this Conference have shown clearly that the scientific problems of the Pacific are not one-man jobs. They are either too complex to be grasped by one mind or require masses of data impossible to be obtained even by a Methuselah. Such problems as we have discussed here can be

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successfully attacked only by coöperative effort and that on a generous scale. Whether or not we like the feeling, we might as well humbly recognize that problems whose significance justify a lifetime of devoted effort, are too big for one man or for one institution.

Our discussions have shown that the facts, methods and conclusions of one group of specialists are closely interwoven with those of other groups; and that even the standardized divisions of science mean little. It appears that a volcano is a physical, chemical, mathematical, and engineering problem as well as a geological problem; that the explanation of a coral reef involves contributions from nearly all branches of natural and physical sciences; and that ethnological problems are at the same time problems in anatomy, botany, meteorology, geology, and psychology, and we might also add in history, economics and theology.

To my mind, the elements of coöperation are: plan, personnel, funds, and the will to coöperate. The first three are essential agencies. The fourth is the favorable environment without which the agencies function poorly or perhaps not at all.

Planning in which many minds coöperate (strangely enough a relatively new conception) insures the selection of fundamental problems, sound methods of procedure and adequate publication. It also tends to eliminate unnecessary duplication of funds and of effort. Intelligent choice of personnel goes far toward substituting expert for amateurish work. The advantage of pooling funds to produce a sufficient amount for a particular project is obvious.

Through the Research Councils of various countries well considered plans may be obtained, and funds are usually forthcoming for projects strongly backed by a large group of unselfish men. Personnel, however, presents a genuine difficulty: the number of existing workers and the crop of promising material in our educational institutions is woefully short of the demands. Likewise the will to coöperate appears to be in a somewhat flabby state. The conditions which surround most individual and institutional work make it easy to find reasons for not coöperating. There seems to be needed a code of ethics which emphasizes generosity, helpfulness, perhaps even sacrifice, and puts the kapu sign on credit, priority, and large museum collections; a code which clearly recognizes that the purpose of

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scientific research is to enlarge knowledge and not to enhance personal interests; that workers in a given field are not competitors but team mates.

My views of the purpose and the desirable scope of coöperation may be expressed in concrete form by outlining some activities of the Bishop Museum designed to make effective the broad-minded policy of the trustees.[1]

To provide for much needed work in Polynesian physical anthropology, the American Museum and the Bishop Museum are jointly financing the work of Dr. Louis R. Sullivan, and the two institutions have an agreement regarding ornithological work in the Pacific. Valued relations with Carnegie Institution have been maintained through the late William Churchill and Professor Crampton whose present expedition the Museum has largely financed. By agreement with Yale University, the generous gift of Bayard Dominick is being expended by the Museum on ethnological and botanical work in Tonga, Marquesas, Austral Islands and Hawaii, and four fellowships, yielding $1000 each, have been established.

For years the National Museum has given assistance, and Dr. William Dall is an honorary member of our staff. Dr. H. A. Pilsbry of the Philadelphia Academy and Dr. C. Montague Cooke of the Museum are collaborating in the study of Hawaiian land shells. The expenses of the work of Dr. Edward S. Handy and Ralph Linton of Harvard University, Prof. Edward W. Gifford of the University of California, William C. McKern of the University of Washington; R. T. Aitken of the Milwaukee Museum and Prof. Arthur J. Eames of Cornell University, all members of the Bayard Dominick Expedition, are being met by the Bishop Museum. The expenses of certain field study in New Zealand are charged against the Museum's budget as is also the cost of printing several manuscripts by students in various parts of the Pacific whose researches are now lost to science because of difficulties of publication. The Museum has profited greatly by the willingness of Dr. Clark Wissler, Dr. Elmer D. Merrill and Mr. Otto H. Swezey to serve as consultants.

With the University of Hawaii arrangements have been made whereby building up a strong library, concentration of

[1] See Address of Welcome on behalf of the Trustees of Bernice P. Bishop Museum by A. F. Judd, President of the Board. Printed on page 947.

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collections, development of marine zoölogy and the training of workers becomes a joint enterprise. Even if funds were available it is unlikely that the Museum would organize a large staff of inadequately paid men, preferring rather to make opportunities for specialists interested in Pacific problems to carry on their work.

The Museum's attitude toward collections is in harmony with its policy regarding investigation and publication. It is proposed to bring together such materials for study as scientists might reasonably expect to find in Honolulu. By general agreement these materials should be gathered: (1) from the 1700-mile chain of the Hawaiian islands; (2) from other Polynesian groups; (3) from Micronesia; (4) from Melanesia. The Museum desires to assist in building up collections in other centers of study and hopes to receive assistance in making the collections within its field increasingly valuable for students interested in Pacific scientific problems.

REMARKS BY MISS TILDEN

If this congress would recommend, or suggest to the inland universities and colleges of the United States and other countries, the establishment of fellowships in scientific departments. such as anthropology, botany, zoölogy, geology, physics and chemistry for research work in Pacific countries, so that their graduate students might be able to become acquainted with scientific problems and opportunities in this part of the world, the result would be of great value to all concerned.

REMARKS BY MR. FRYE

The Puget Sound Biological Station is small and the sum of money it has to spend is not very great. The University of Washington, of which it is a part, is a new institution which has grown more rapidly in numbers than in wealth.

I think the natural field of the University of Washington is northward from Seattle, not because it would not be interested in the South Pacific, but because it is much cheaper to go northward, especially as there is no direct line connecting Seattle with the Hawaiian islands. The lines from Seattle run to Alaska and all of its activities lie toward the north.

But in general I think there are ways of coöperation and the first of them is by exchange of literature. We would like to

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know what is being done in the Pacific because we live on the Pacific. In trying to work up a library I have found a tremendous difference in the attitudes which the different institutions take. Some institutions like the Smithsonian and the United States National Museum are very liberal; others equally large, will exchange only an equal amount of material and as our publication is only in its second volume you can readily see that we are not in a position to exchange on their basis. Furthermore, the Puget Sound Biological Station is 100 miles from Seattle and duplicate copies are very desirable.

One of the difficulties we find especially in our station is that we cannot get at what scientific men are doing in Japan and the Latin countries of South America and Mexico because their publications are written in Japanese and Spanish. I believe it would be wise to have these works which are printed in Japanese and Spanish reviewed in American journals.

Another point is that while I might like to do things in the Pacific the cost of going from one country to another is too great. For instance, the shore regions of New Zealand are like those of the Pacific coast of America and I should like to see them and very probably could get a year off. I would also like to visit the Philippine Islands to see what mosses they have. There are a great many things which need looking into but the cost of transportation is too great.

I wonder if this could be done; if this congress could recommend to the various governments that the fares of scientific men be reduced when the scientists are prepared to do a definite thing and the Government is prepared to approve that work, the idea being not to have these fares free, but that steamship companies should not make money out of the scientists who are doing something for the benefit of others.

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SYMPOSIUM ON TRAINING SCIENTISTS FOR PACIFIC WORK

(From the stenographic reports of the General Session, August 18, 1920)

REMARKS BY MR. YAMASAKI, CHAIRMAN OF THE SESSION

If scientific work in the Pacific is to go forward, a suitable corps of well-trained workers must be provided and organized. In Japan, at least, the number of workers interested in other parts of the Pacific is unfortunately small. I believe a basic difficulty lies in the character of the elementary schoolbooks used in various countries. They contain little information about the Pacific and the information they do contain is a mixture of truth and error which is misleading and sometimes harmful. Textbooks for the lower schools which gave sufficient information about the islands, people, plants, animals, and history of the Pacific might interest a number of youths who later on would feel drawn to add to our knowledge of this vast area, about a third of the earth's surface.

Without taking more of your valuable time, I will ask President Dean to give his views, and I hope that others will follow.

REMARKS BY MR. DEAN

This Conference is concerning itself with what should be done in the Pacific and how to do it. There is very closely allied with those questions the other one of "Who's going to do it?" And that, I take it, is what we are concerning ourselves with this morning. There are not enough able young men going into scientific work. We have the problem of getting young persons to take up scientific research and of training them so that they will be competent for the work which has to be done.

This dearth of properly trained young men going into science is sometimes laid to the insufficient financial reward, sometimes to certain social and psychological factors which discourage men from going into science.

As to the financial end of the proposition, it seems to me perfectly obvious that there is a base below which you cannot go if you are dealing with persons who must earn their own livings. Of course there are a certain number of persons who do not have

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to earn a living and that do not have the abiding stimulus of necessity which is usually the one thing which we can depend upon to keep men at work. The conditions of employment in scientific research should obviously be such that a man can live a normal life and can look forward to having a family and a reasonable degree of the enjoyment of this world's goods. Whenever you get hold of a young man who has a family, the chances are all in favor of his being very jealous of his children's future and anxious to provide for them the things which he deems necessary for their education and getting them launched in the world. I am afraid that the compensation in scientific work, with the present conditions of living, is below what you can expect men to live on. Financially, the thing is not attractive.

There is the other phase of it, the psychological reasons why men are not attracted into scientific pursuits. It isn't always the fact that we don't get a large income; it is the fact that people think we can't get one that bothers us. There is a feeling on the part of young men of universities that the mark of success and the mark of a man is the amount of money which he can accumulate. That isn't due to the university environment, but to the environment outside the university. To meet this it must be made clear that there is adequate financial support and that the accumulation of knowledge is a basic thing, a thing worth paying men to do. That is one thing which scientific men and this Conference should insist upon. And another is the creation of the view that scientific work is a man's job, that men do it because it is worth while, and that men go into it not because they are not good enough to go into something else but because it is a real man's work and as worth doing as running a bank or a shoe factory.

Turning from these general considerations which have to do with the attitude of men toward scientific work, we come to the specific question: What kind of training is needed? Dr. Yamasaki touched on a very real and very important need: that way back down in our lower schools there should be more information about the Pacific Ocean and the countries which border on the Pacific. There is a mixture of gaps of information and of misinformation—a great deal of the latter—in the education of our children. The islands of the Pacific Ocean and the countries which lie around the Pacific Ocean are neglected in the textbooks which we have in the lower schools. People have

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not waked up to the fact that there is a tremendous number of people around the Pacific and that they are doing things which are worth while.

In the colleges and universities we find that the undergraduate student comes to us with the attitude of wanting perfectly definite, finished statements; that he has the average man's intolerance and the average man's laziness in arriving at judgments himself. And the inability to analyze a proposition into its elements and come directly to the center and core of the matter is one of the fatal deficiencies of the undergraduate students. What we need in the handling of these youngsters is a teacher who can lead them, a reliable, independent teacher who can teach them to observe accurately and think clearly. That is the kind of a teacher which is needed in the elementary courses in the universities. And then in the last years of our university work we should more and more influence the student to work on some job—to begin to feel responsibility. That can be done by giving him some special job, something to look up, and to carry through to a finished conclusion so that he can say, "That thing is done." This is one of the things that our juniors and seniors in college ought to do.

There is one specific thing that has to do with training for the work in the Pacific. You will find that English is a language which is taught in the high schools and universities in China and Japan. In American schools and colleges we are paying almost no attention to the other Pacific languages. It is absurd and exceedingly unwise to know nothing at all about their languages and have to guess at what the other nations are thinking about except as they tell it to us in English.

There are a great many young men who have managed to get through an undergraduate course that would like to go into scientific work, but they find themselves at an age of perhaps twenty-one or twenty-two years confronted with the problem of self-support, and if they go into scientific work they are going to be very much up against it if they are going to make a living. So, it is of first importance that there should be fellowships in sufficient numbers so that we can get young men to continue their training in scientific work, and I wish that these things could be looked upon not as charitable gifts but as compensation for work done: in other words, that a man who is working on a fellowship should feel that he has a job and that

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he is being paid for his work. That puts a little different aspect to the thing and it appeals to a little different side of a man's nature.

Finally, I think that it is essential that we should have a very large degree of coöperation between the scientific institutions which exist around the Pacific. I should like to see it made possible for the student to go if necessary from one place to another without losing time in the work for his degree. For example, if a young man from some university away from here wishes to come here to study about the volcano of Kilauea, it should be perfectly possible for him to come over here and work under Dr. Jaggar and his work here should be counted as a part of the regular work for his degree. That means the drawing together of the graduate departments of the institutions bordering on the Pacific and the research institutions so that men can move about from one place to another and get to know and utilize the opportunities that exist. We need a clearing house of information about these opportunities so that we may capitalize them in the training of young men for future scientific work.

REMARKS BY MR. CHILTON

Dr. Dean very clearly and thoroughly laid out some of the fundamental processes by which we can expect to have a trained body of men. While he has pointed out the necessity for having adequate pecuniary reward, I wish to emphasize another very important requirement, and that is, the material used in the training. From that point of view it is the teacher who is the essential person and we can not hope to get a thoroughly trained and inspired set of workers unless we have the teachers who will direct their attention to the value of science.

I wish to follow up this point. You will doubtless remember many of you, in 1858 there were two very important papers read before the Linnean Society of New South Wales, one by Alfred R. Wallace and the other an unpublished work. The principle of natural selection was first becoming popular. Darwin's "Origin of the Species" in the hands of a younger body of naturalists caused much stimulating work, and the result was an increased knowledge of natural history. Wallace drew special attention to the fact that both Darwin and himself had traveled extensively and that he thought the experience resulting from that travel had a great deal to do with their work. It

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might be urged that they were men of exceptional ability, but there is a great amount of force in what Wallace has said. Those of us at this Conference will, I think, agree that even the small amount of travel in coming here and the stimulation of meeting others have been of immense importance. I only regret that such opportunities did not come my way twenty-five or thirty years ago.

This leads me to the point that if we are going to train workers it is important that we should have some means by which they can travel to other parts of the Pacific to see what is being done and compare it with their home work. What I should like to see as a result of this Conference is some provision made toward that end. Naturally we say that this should not be the only meeting of the Pan-Pacific Scientific Conference. It is very desirable that there should be another and if we could arrange to have the next meeting in Japan, Australia, or New Zealand, I am certain the stimulation and inspiration arising from the meeting would be of immense value in encouraging men to study scientific problems.

It seems to me we might receive great benefit through interchange of teachers and graduate students. It is the teachers we want to equip with a knowledge of Pacific regions and to enable them to get the advantages of travel we have spoken about. I am impressed here with the great facilities for interchange of teachers across the Pacific. Some years ago I was in London at a congress and the question of interchange of students and teachers came up, but so far as New Zealand and Australia are concerned the question of distance has been so great that no practical result has yet been attained. Perhaps we are too closely allied in interests. Here in the Pacific we have not those difficulties. Out in New Zealand we are somewhat isolated. It wasn't until I came here that I understood the great facilities here for supplementing our work in New Zealand. In the study of geology those who are going to be specialists could not do better than come here to study volcanology. I am perfectly certain that within a month with the facilities offered by the Volcano Observatory they would learn far more of volcanology than in one or two years in the ordinary way in their own country. On the other hand in New Zealand and other places around the Pacific we can offer facilities for studying the action of water in eroding great river beds

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and in forming great plains. Then again in connection with zoölogy here in Hawaii you have a perfect center of entomologists. So far as I am aware, there is greater opportunity for the study of entomology here than in any of our British universities. In New Zealand we have similar kinds of problems to solve and if we could send students to Hawaii for a few months I am sure they would gain very greatly. On the other hand, in New Zealand we have a white race with a small native population and if political economists can come and see something of the mixture of races here they would gain in a very short time what would only come with a large amount of study at home.

I hope there will be some sort of coöperation resulting from this Conference by which it will be possible for students and graduates to pass from one country to the other.

REMARKS BY MR. BOWIE

I have been very much impressed with Dr. Dean's talk. We are in a bad way scientifically. Probably it is largely our own fault. In the first place, scientists are not good missionaries as a rule. You hear of men in every line of endeavor enlightening the people concerning their work by means of addresses, and otherwise bringing their work to the people. It seems to me the great field for scientists here and all over the world is to get in close touch with people of education. It is said of scientists that they have shown the world how to organize but that they have not organized themselves, and until we do get behind this movement to get science to the front we will have to depend upon a few patrons.

I would like to speak of the situation in the government bureaus. They offer great possibilities for creating workers in science. In the United States most of the geologists in the colleges and outside have at one time or another been in the Geological Survey of the Government. Many physicians and chemists have been in the Bureau of Standards. But today the governments are not attracting men. No career for a man so far as scientific success is concerned, is offered in the government bureaus. Our government does not hesitate to spend anywhere from $3000 to $10,000 to get a lawyer, but thinks a scientist should come to the government for $1200 or $1500, and that is what we are offering in nearly all our entrance positions. This situation must be corrected. We must let the legislature

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know that science is a profession and that our work is just as necessary and probably more so for the welfare of humanity than many other lines. We have got to pull science out of the mud ourselves. We need patrons, but do not let us sit back and hope for wealthy men to come forward. Let us get behind the problem ourselves.

REMARKS BY MR. FRASER

I am afraid that in Canada as in other places on the Pacific, we are very much in the condition that has to be satisfied with the well-known prescription for making rabbit pies: "First catch your rabbit." At present there are very few scientists in Canada interested in the Pacific, partly because the Dominion as a whole is overweighted on the eastern side, the whole plains region and all of the eastern interior as well as the seaboard gravitating toward the Atlantic rather than toward the Pacific. That leaves only the province of British Columbia interested in the Pacific. So far as training is concerned, there has not been very much chance. The University of British Columbia is only five years old and during those five years there has been a great deal of detachment of effort on account of the great war. The work of the Biological Station faces the difficulty that there is an eastern as well as a western station, and it is much easier to get the men of the east to work on the Atlantic seaboard than on the Pacific.

One of the reasons for the scarcity of trained men that has not been stressed is the demand for scientists in commercial lines. Until recently scientific requirements had only to be stated in sufficiently plain terms to induce men to carry on research in any particular field. Now commercial openings are becoming so numerous that the purely scientific work has to be very entrancing before it will take men away from the commercial field.

The blame for the failure to train scientists has been placed on the university, the high schools, the middle schools, and also on the public schools. I have taught all the way up the line, so suppose I can take a little blame wherever it falls. It seems to me that so far as the public schools are concerned one of the great dangers in our present education is in making things too easy. We have textbooks of a great variety and teachers are trained in many lines to feed the boys and girls to

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such an extent that they do not have to do anything themselves. Consequently a little later on when fields of research are presented to them, they are too lazy-minded to be particularly interested unless they have been picked up on the way by some enthusiastic teacher who has been able to inspire them.

Another difficulty it seems to me in the education of the primary schools is that we have become slaves to textbooks. It is a good many years now since I came to the coast. At that time we were teaching such subjects as physiography in which textbooks are almost superfluous, nevertheless the material in the printed books was used. Very often books are based on material that has never been seen, and when the students come to the university, a very large number of them have already formed a hatred of zoölogy and botany. We have no definite textbooks, no interesting story-books based on local natural history, and it seems to me that until something is done along that line we can't expect to interest children, and through them the parents and other members of the family. It is the general apathy toward scientific work that prevents our getting young men to take up scientific work. Many Sunday newspapers and periodicals and other books write a number of fake stories of scientific work and people have become so sick of them and have found out their fallacies so often that they are rather afraid to put any faith in any scientific articles at all. It seems to me a great change should be made in that regard and that scientists should publish some real facts regarding the various phases of Pacific science.

Another point is the fact that children spend a large portion of their time at moving picture shows. Why could we not do a great deal to educate them along scientific lines through good pictures which would show, for example, life history and rate of growth. If we could only educate the people at large and the children from the start right on through, there is no reason why we should not get support to carry on the plans we are interested in.

REMARKS BY MISS TILDEN

There is one phase of the training of scientists for Pacific work which should not be neglected: the training of young scientific workers in the countries visited.

As a result of this Conference, there will be undertaken, in all probability, a considerable number of surveys, covering

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such fields as anthropology, biology or geology, based upon general or specific lines. It is to be supposed that the personnel of such surveying parties will be made up largely of investigators from the country sponsoring the project. It is suggested that young people from the Pacific countries under consideration be added to these parties and trained in the kind of work being done. These young persons then, remaining in the region studied, would compose a body of well-trained students capable of continuing investigations in the various branches of science, along the lines followed by the visiting experts.

For example, it is proposed to make an algological reconnaissance of the entire coast line and islands of the Pacific Ocean, the work to be pursued by two exploring parties.

Now, when these algological workers begin their collecting on the shores of Chile, for example, would it not be a good plan to have one or two advanced students in biological science from the University of Santiago join the party? These young people could to some extent act as guides in the location of good collecting fields. They could act as interpreters in the collection of information from the people living along the coasts. In the end they would return to their institution with a knowledge of the most approved methods of carrying on this particular kind of investigation. In all probability they would be encouraged to continue their work and perhaps out of this there might develop the establishment of a biological station on the Island of Juan Fernandez.

The delegates from Australia, New Zealand, and Japan give assurance that they will furnish the visiting algological party with several specially trained young scientists who will both give and receive assistance in the work of studying the rich marine vegetation of those countries. On the other hand, in the Polynesian island groups, at any rate, the natives will be found to be in possession of a botanical training of their own, of no mean value. The Tahitians have names corresponding to our generic and specific plant and animal names and they are very keen observers. Young men and girls can be found who would prove to be of the greatest help to visiting scientists. No doubt arrangements could be made for their continuing to keep records, or to supply specimens gathered at other seasons of the year.

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REMARKS BY MR. COTTON

If we start at the beginning and examine what is necessary for the training of men for Pacific research or any other type of research, we find that fundamentally it depends upon the teacher in the university, that is to say, the university teachers must inspire their students in the work which it is their duty and privilege to do. What I have to say, I believe, is true of all Australian universities, but it is certainly true of Sydney University. In the first place we have an under-staffed university, which fact, although it does not and cannot prevent the mental attitude of its teachers in inspiring the students to do scientific work, does hamper them very considerably by placing undue burdens on their shoulders. It is a matter we have to consider and a problem we have to solve.

In the second place, this Conference has shown very clearly that the problems of Pacific research center very largely about those of geography and anthropology. There is at present in no Australian university a chair in either of these subjects. Sydney is establishing a minor chair in geography next year. Surely we should have chairs in geography and anthropology in every Australian university, and I think when we go back to our own countries this is a matter in which we will all unite in emphasizing very strongly.

A third point is that we have no graduate schools. There may be minor scholarships and fellowships which enable advanced students to proceed for a year or two on something less than a living wage and enable them to carry out certain scientific work, but such students must content themselves with such assistance and advice as they can obtain from the overworked teaching staff of the university and from other scientific men in the community. There is a real need then for some graduate courses in Australia. This brings me to the fourth and last point, and that is if we are to have extended scientific work we must have some such system of fellowships as Professor Gregory has arranged for the Bishop Museum to enable men to carry out such work. Speaking for Sydney only, we have one such fellowship available for work along the lines which have been indicated by this Conference and that fellowship is specifically allotted for research in agriculture, so that you see these deficiencies hamper us a good deal. We must set about to see that they are made up so that our program of research

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may get under way and be carried on continuously. I think perhaps the greatest advantage we, as delegates from Australia, will reap from this Conference is that we have had our attention called to these great Pacific problems and have been made to realize more than ever those deficiencies which exist in Australian institutions. This knowledge will inspire us to work as hard as we can to put those matters right.

REMARKS BY MR. A. F. JUDD

I speak from the standpoint of a trustee of Punahou, a large preparatory school in Honolulu with some 800 students. As I view it, the entrance requirements to universities have resulted in a great change in pre-college education from the time I was a student preparing to go to a university. Twenty-five or thirty years ago the rudiments of science were instilled in us before we got into the high school. Zoölogy was intensely interesting. All the beauties of growing things were made known to the boys and girls. Now as the result of the pressure to comply with college entrance requirements, this is no longer possible. What time is available is devoted to what is called biology. and it is generally taught from the microscopic standpoint without reference to the glory of the out-of-doors. Science is taught but without romance. It is only a means of getting into college.

If men are to be interested in science we have to touch the imagination of the students in the early years. I would like to venture a guess that every scientist in this room had a strong slant toward science before he left high school. We have to interest them early. The colleges and universities must be appealed to to encourage science in secondary schools.

REMARKS BY MR. EVERMANN

The cause of the scarcity of men trained to do scientific work is very deep seated. The method of instruction in the schools lies, as Mr. Judd has said, with the elementary schools rather than with the high schools and colleges. The average child is a born naturalist. He asks questions all the time. He has learned more in the first few years before he enters the public school than he ever will learn in all after years. He begins to ask questions of his teachers which they are not always able to answer, and his scientific tendencies are stamped out by the

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time he reaches the eighth grade. Count the number of teachers who know how to teach botany and zoölogy. My observation of natural science as taught is that it is not only worthless but that it is pernicious. It does not foster a scientific spirit but rather leads away.

The Government trains scientists to do a certain type of work. Dr. Dall wanted to find some man able to identify shells and wrote the colleges asking for such a person. He could not find one among all the colleges of the land.

The question of pay has generally been answered by saying that biologists are always willing to work for love and a few extra copies. That is too largely true and to our discredit. Biologists and zoölogists should be considered on the same plane as chemical engineers and should have the same pay as the physical scientists get. So it is our own fault, I am sure, but when we have the right sort of instruction the situation will be in a degree remedied.

REMARKS BY MR. VAUGHAN

I should like to go back a step beyond the one mentioned by Mr. Judd, which has to do with children not only in the lower grades but children perhaps even in homes. As Dr. Evermann has said, every child he has ever had much to do with is by instinct a naturalist. They are interested in everything around them and the most they need is sympathetic encouragement. If you answer all the questions they ask, even if they are very troublesome, you are doing the best kind of propaganda for the general appreciation of science. I also believe that a sympathetic attitude should continue right on up through the various grades of the schools. I think also that part of the trouble lies with the universities, but who is responsible for their attitude? I think it will always come back on the general body of graduates who support the universities.

My topic was the training of geologists for work in the Pacific. The first thing we need is enthusiasm and continued interest in the work. That has already been well covered. One thing we particularly need to get into the training of geologists is the idea that geology as a science has to deal with the history of the earth and with the utilization of geological resources. Geology embraces many fields and involves many branches of science. Research in all these different lines is needed if we

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are going to understand the history of any part of the earth. We need specialists. No man can cover all of these different fields and do the work with the desired thoroughness. At the same time he can appreciate that problems are there and know where to look for help. If you are going to understand the history of the whole region you must throw emphasis on the whole thing. The difficulty in obtaining geologists for research is the same as in other subjects. As a professional career any competent geologist can get a rather large remuneration of $5,000 or $6,000, or maybe $10,000 a year. Experienced men get anywhere from $15,000 to $50,000. The real difficulty is to keep them devoted to research, and to do this we need to recognize the value of men in research work. It will not be long before we have a similar condition in law and medicine and in other learned professions. Men in private work should also be recognized. I do not feel particularly depressed when I find some of the brightest young men going off with commercial concerns for I have noticed that they never lose their interest in scientific research.

Dr. Gregory is right in his contention that a man should think in terms of the Pacific. I believe the number of geologists who work in the Pacific will be increased as soon as opportunities are offered for the men to devote their concentrated attention to the region. Please remember that in training geologists for research work we want men who will regard the regions as part of the earth which must be studied with reference to the history of the rest of the world.

REMARKS BY MR. BARTSCH

I have been very much struck to find here in Hawaii so many different shells and have wondered what might be the scientific names. I may trace them all to the land shell. You have that beautiful group of Achatinellas here and many collections of them throughout the city, and yet in spite of the tremendous interest in this group you have had very few who have devoted themselves to the systematic study of these beautiful organisms. I have wondered why it is necessary to call on the men on the mainland as specialists. Mr. Judd and Dr. Evermann, I think, have touched the keynote—a lack of teachers.

It is interesting when you look back in the history of science in America to find the stages through which it has passed.

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When I attended the high school we had to make a herbarium of one hundred plants and identify each one. Those hundred plants are my friends today. They form the nucleus of a knowledge of botany which has been the greatest inspiration that has come to me. I remember when I went to the Philippines I saw trees which with us were mere shrubs. I had to ask Dr. Merrill on several occasions their correct names. They were giant cousins and I had recognized the relationship. I have never once been lonely on account of this bit of information which I gained through the study of botany.

Let us look at the difficulty. I do not think it is with the primary schools at all. In the early classes the teachers tell the children something about the common animals. The fault lies with the high schools where you find the microscope and wonderful rows of shelves and cases filled with sections. Then it is so easy once you have a microscope to send to the University of Chicago and get pieces of other plants that grow in your backyard but of which you are unaware, and hand to the students for the making of other sections. In other words, we have gotten into a machine-made biology, and it is so easy and pleasant for the ladies who are teaching these subjects to simply take a specimen and make a microscopic section in order that we may get at the real fundamentals of things, for once upon a time the pendulum swung in one direction and we believed there was nothing beyond systematic zoölogy. Then we came to the point where certain biologists of extreme ability pointed out that after all we might find the cell-like structure of the various organizations in unity and we might find there a panacea which would remove all those disastrous questions which have assailed systematic zoölogy as far as religion is concerned.

I am hoping it may be possible some time to get teachers who can teach the old-fashioned zoölogy and botany in the high schools with all the other information added. I had a most interesting experience last year. (I might say here I have had charge of botany in the George Washington University for almost a quarter century.) We made an attempt to get a man who would be willing to give as a foundation a systematic course in botany, as a foundation course I repeat. He has not been found yet, in over a year's time. I feel sure this is what we should look forward to if we expect to re-awaken that interest on the part of the public which our natural sciences deserve.

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REMARKS BY MR. RICHARDS

One thing this Conference should aim at is to see that financial remuneration for scientific work is enhanced. During the war all nations felt the necessity of the actual service of scientists. They were promised all kinds of things and all sorts of ideas were put forth as to what must be done, particularly in England, where scientists were notoriously ill paid. It was decided that the first thing to do was a particular job, and the job went to a particular scientist. True, to a considerable extent the reward of scientific work has been increased, but the work of the scientist is necessary, and the sooner the people concerned realize this, the sooner will adequate compensation be provided.

In Australia the universities put forward a scheme to the Commonwealth government for establishing certain fellowships for carrying on research work in the Pacific islands. The Commonwealth government went into the matter but is not likely to put up the money, although it is favorably inclined to the view that the work is necessary. Some extra influence is needed other than schemes from the Australian universities. If we can go home from this Conference and absolutely convince the Commonwealth government that it is their job to carry out this work, it will be of considerable help.

REMARKS BY MR. WOOD-JONES

There is at present no federal bureau of anthropology in Australia nor is there any institution in any individual state which possesses a properly staffed and equipped department for the conduct of anthropological work.

A chair of anthropology is a great need in Australia and its incorporation with one of the large universities having teachers and research facilities is much to be wished for. A very large store of anthropological material, both physical and cultural, is collected in the museums of Perth, Adelaide, Melbourne and Sydney; and there is a great need for the working over of this material upon modern scientific lines. More especially is this want felt in regard to the examination of the skeletal remains of the peoples of Australia and surrounding Pacific regions.

The museums in which this material is stored are not directly attached to the universities or other teaching bodies, and it is much to be desired that, pending the establishment of

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such a chair of anthropology, a coördination of effort such as we have recently effected in Adelaide might be brought about by which a university teacher interested in the study of man may be appointed Honorary Curator of the Section of Anthropology in the museum. An undue amount of anthropological material remains in the hands of private individuals in Australia, and this private appropriation, especially of large series of crania, should be emphatically discouraged.

The present speaker has no doubt in affirming his belief that plenty of young men of the best sort would be ready to take up the work were a chair of anthropology established in one or more of the Australian universities. Anthropology cannot thrive in a teaching center when it may or may not happen to be a more or less interesting hobby of the Professor of Anatomy; much less can it thrive if its sole exponents are detached amateurs working without coördination and often in actual rivalry. It is much to be desired that one outcome of the deliberations of this Conference will be a stimulus given to the Australian delegates such as will enable them to influence public and official opinion in Australia and lead to the establishment of a chair of anthropology in one or more of the universities.

REMARKS BY MR. GREGORY

I am a confirmed optimist and I believe scientific men are going to be found for work in the Pacific. I also believe that to obtain them may involve changes in thought and action which appear somewhat radical.

The scientists directly concerned with the Pacific are few in number; workers must come from continental countries, from educational centers which give little thought to the great Pacific region. To do the best work, I believe it essential to think in Pacific terms. There is something about the sentiment or feeling that "this is my part of the world and my job to solve its problems," which reacts on scientific workers. Few of us have that attitude. In moments of abstraction our minds unconsciously turn to Europe or to the Atlantic seaboard or perhaps make the jump to Japan or China. Our friends from New Zealand know all about England but are surprised in Hawaii. The Hawaiians, in turn, know little of their English-speaking brothers to the south. It is difficult for us in Honolulu to realize the importance of a knowledge of Japan, Java, and Australia, and that to

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know something of the working of a Chinese mind is of greater immediate value than familiarity with the politics of New York City. Most of us are Atlantic-minded rather than Pacific-minded, but somehow we should develop a Pacific sense. I believe it is a conditioning factor in the training of scientists for Pacific work.

I agree with Dr. Yamasaki and other speakers that the lack of interest in Pacific things is in large part due to school text-books. Pupils in Hawaii learn about the Pacific from geographies made to sell east of the Mississippi river, and may have been written by teachers whose first-hand knowledge of the world is gained from the streets of Boston or New York, supplemented by a trip to Europe. The same condition prevails in other Pacific countries. It may be found necessary to write textbooks which will give an adequate picture of the Pacific, for certainly no young man will respond to the call for scientists who has not had his attention drawn to the Pacific as a region of interest and opportunity. I believe it is appropriate in our classrooms, through the press, and by personal interview to show that Pacific science is an enviable career—a job for red-blooded men.

I agree with Dr. Bowie and others that inadequate remuneration makes it difficult to obtain men, but I do not rate this obstacle so highly. I have never known a capable student who earnestly wanted to get into science who did not have the opportunity to do it; but I know many men without money who have gone into science and soon found themselves relieved of financial worries. To my mind, the seriousness of the situation lies not so much in the absence of opportunities for a scientific career as in the lack of enthusiasm for the scientific life of disinterested service. However, as conditions exist today, it seems desirable to make exceptional effort to increase opportunities to take up Pacific work. With this in mind Yale University and Bishop Museum have combined in founding four fellowships with an annual stipend of $1,000 each, available for professional workers interested in Pacific problems. If this proves to be a satisfactory procedure, I trust that other institutions will make similar provision.

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ADDRESSES OF WELCOME

ON BEHALF OF THE PAN-PACIFIC UNION

By C. J. McCarthy, President of the Pan-Pacific Union and Governor of Hawaii

Mr. Chairman, Members of the First Pan-Pacific Scientific Conference, Ladies and Gentlemen:

In the name of the people of the Territory of Hawaii I bid you welcome to that which we like to call the Paradise of the Pacific.

In the name of the Pan-Pacific Union I also bid you welcome to that which they like to call the Cross-Roads of the Pacific.

I wish to thank those who have come here to attend this Conference. The representation has been much larger and greater than we expected. I believe that during your stay here you will see that both titles really belong to this beautiful group of Islands.

The question might be asked—What is the Pan-Pacific Union? What does it represent? What does it stand for?

In Hawaii we have people from many countries which border on the Pacific. These people have come together and organized the Pan-Pacific Union. Its membership consists of people from all these countries. The foundation stone of this organization is that all these people know one another as they should and it stands for the brotherhood of men. The organization realizes that the Pacific Ocean is to become the theater of vast commercial enterprises.

What do we know of the Pacific? Comparatively nothing.

Most of the problems belonging to the Pacific and the development of the Pacific are scientific in their nature. That is, they should be studied from a scientific standpoint so as to get the best results.

Hawaii occupies a great scientific position in this respect for out here in the midst of the ocean we have a scope of everything which surrounds us. We are able to consider everything relating to the development of this great ocean.

I saw the other day a chart of the Pacific. This chart showed how little the people already know and it shows the

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possibilities for future improvements and an increase in the knowledge of what we should have in order to develop this great ocean.

Hawaii itself has its problems. I believe that you gentlemen will find in Hawaii a veritable museum for scientific investigation. I believe that in the program it is intended that at the end of the week you are to visit the Island of Hawaii. There in the Volcano of Kilauea you will see the world in the making. As you travel along the Kau and Kona coast you will see recent lava flows and older flows; the recent flows being barren without any vegetation and the older flows, as time went on have disintegrated into soil and vegetation is beginning to grow. As you get back to Hilo from the trip to the volcano you will see soil twenty feet deep. All this will afford material for investigation.

I wish to thank you for your attendance here and hope that your stay will be a pleasant one.

This morning we have already given you a touch of liquid sunshine and we have that same thing by moonlight.

I thank you.

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ON BEHALF OF THE UNIVERSITY OF HAWAII

By Arthur L. Dean, President of the University

Mr. Chairman and Members of the Conference:

It is a great pleasure to be able to welcome the delegates to the First Pan-Pacific Scientific Conference in behalf of the University of Hawaii. This institution, under its present name and with its present organization, is scarcely older than this Conference itself. Twelve years ago there was organized in Honolulu a College of Agriculture and Mechanic Arts, the last one of the so-called Land Grant Colleges to come into existence. This institution developed slowly and was, in its early years, restricted to work in agriculture, engineering, and a related group of the sciences. As it became more firmly established in the Territory the necessity for a wider scope of instruction and investigation became evident. The Legislature of this Territory which met in the spring of 1919 decided that the foundation for a Territorial University should be laid, using the plant and organization of the College of Hawaii as the beginning of an institution of greater scope and, we hope, of wider usefulness. Plans for the immediate future call for two undergraduate colleges, a College of Applied Science which is substantially a continuation of the former College of Hawaii, and a College of Arts and Sciences. In this latter college there will be found those students whose interests are not primarily scientific or at any rate are not directed to the applications of science.

The University will not rest content, however, with undergraduate instruction alone. A certain amount of graduate work and of research on the part of the advanced students and members of the faculty has been going on in the College of Hawaii for a number of years. This aspect of the University's work is bound to become more and more important and to relate itself with other research organizations in the Territory and elsewhere.

The University is supported in part by the funds derived from the United States Government under the Land Grant Acts, amounting at the present time to $50,000 annually, and in part by appropriations made by the Territorial Legislature. This latter body has in recent years adopted a far-sighted and

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generous policy in the support of higher education which we hope will be continued.

The University has well equipped laboratories for a number of the sciences and the facilities for scientific work are being added to each year. There is now under construction a laboratory for marine biology in connection with the Aquarium which has recently been transferred to the care of the University. Special provision has also been made for investigations in seismology in which we are particularly interested.

It is the hope of the members of the University that we shall be able to cooperate with you in carrying out the purposes of this Conference and that this cooperation will not cease with the end of our sessions here. We may hope that this Conference will bring about a sense of the community of interest in scientific work in all parts of the Pacific. In the future we hope that the different scientific institutions can keep in touch with one another for the exchange of ideas, of workers, and of students. You may be sure that the institution which I represent will be only too glad to cooperate in any or all of these ways.

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ON BEHALF OF THE EXPERIMENT STATION OF THE HAWAIIAN SUGAR PLANTERS ASSOCIATION

By H. P. Agee, Director

Mr. Chairman and Delegates:

As scientists visiting Hawaii, your interest may sooner or later be attracted to the Hawaiian sugar industry, and the part that applied science has taken in placing this industry in the somewhat unique position it occupies at present.

From the early days the founders of the sugar industry in Hawaii have appreciated the advantages to be derived from cooperation, and the benefits to be realized by the application of science to their agricultural and manufacturing enterprises. One evidence of this understanding on their part is the Experiment Station of the Hawaiian Sugar Planters' Association. I speak for the staff of this Experiment Station in bidding you welcome to Hawaii and in expressing our pleasure in having you here. We wish to extend to you an invitation to visit our Station, and to become acquainted with the work we have in hand.

Our Experiment Station differs from most institutions of this type in that it is operated in entire independence of any government funds or private endowments. Our work is conducted as an integral part of the sugar business of Hawaii. Our investigations and researches are, in consequence, planned in accordance with the economic questions pertaining to sugar production under the diverse climatic conditions of the four main islands of the group.

Our Station passed its twenty-fifth birthday in April of this year, it having had its beginning in 1895. Prior to this time (Hawaii in 1895 was producing 150,000 tons of sugar a year, about one-quarter of the present output) the planters had formed an association which dealt with the supply of labor, and met periodically to discuss the practical questions of the industry.

Commercial fertilizers were imported as early as 1878. The problem arising as to the proper use of these materials led to a call for scientific aid. In an early report by a planter, dated 1883, we read of the concern felt at that time:

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The question of fertilizers for our fast exhausting soils is becoming a very serious one. When it is realized that from 20 to 60 tons of cane is a very common yield per acre on our plantations; it requires no prophet to foretell the decline of even our richest soils.

The story of how the Hawaiian planters have continued to crop these "fast exhausting soils" of 1883, year after year, cane crop following cane crop, with little or no relief in the way of fallowing and green manuring—how in doing this they have not ony maintained but have steadily increased the yield per acre until the record yields of these lands are not ones which sprang from the virgin fertility of a generation or more ago, but the crops of today, after 25 to 50 years of continuous sugar cane cultivation—this is a story with few parallels in the history of agriculture.

It is a story of industry, perseverance, cooperation, and applied science. It has its dark chapters of struggle and discouragement; there have been serious problems all along the way. It tells of how the laboratory, the technical library, the trained specialist, have taken a prominent part in dealing with these problems, sustaining and upbuilding the sugar agriculture of these islands.

The first efforts of the Experiment Station were devoted more particularly to agricultural chemistry, the soil and fertilizer questions occupying much of the time of the early workers, leading to some splendid investigations on the soils and lavas of Hawaii by Dr. Walter Maxwell and his assistants.

It was in 1903 that the cane fields became infested with leafhoppers, and so severe were the ravages of this newly introduced pest that the industry suffered disastrous losses, and was actually threatened with ruin. This led to the organization of a department of entomology and the engagement of the best talent obtainable. The account of how the pest was placed under control by the introduction of a very minute insect—a natural enemy obtained from Australia, whence the pest had come—is one that you should hear because it is a striking example of how science can benefit agriculture. I hope that your program committee will call upon our entomologists to tell you of this work. Both Mr. Swezey and Mr. Muir had a part in the undertaking and can give you first-hand information. The control of the cane borer by a tachinid fly, for which Mr. Muir searched the South Seas some years ago, is no less interesting, and likewise extremely

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important to Hawaiian sugar production. The control of these two pests and the more recent subjugation of a white grub that gained access to the cane areas on Oahu are three signal achievements of economic entomology.

Not only have our fields suffered from insect pests, but plant diseases have also reaped a heavy toll. Investigations of the cause and character of these sugar cane diseases have led to relief, both by the choice of resistant cane varieties and the modification of agricultural practices to meet the situation. The study of foreign diseases in Java, Fiji, Australia, and other regions by Dr. Lyon has resulted in much information for the guidance of our agriculture. Sugar cane pathology is primarily concerned with preventive measures.

Following the leafhopper disaster of 1903-04, stringent quarantine was established against the introduction of cane from abroad, and almost simultaneously the Station began the propagation of new seedling varieties. Of the first 5000 seedlings propagated, about 1905, by Mr. C. F. Eckart, then Director of the Station, there is one cane, H 109, that is being adopted by the plantations of the irrigated districts. These are spreading it very rapidly. Fortunately it is a variety that thrives where the old Lahaina cane succumbs to root disease. There are now probably 25,000 acres planted to this seedling and it promises to be a boon to the industry.

An important feature of our work that has been expanded rapidly during the past years, is the field experiments, a co-operative undertaking between the plantations and our agricultural department. There are more than a hundred of these field tests located on the plantations with a view to solving questions that arise as to the best field practices. The extensive use of commercial fertilizers and the most profitable way of utilizing these expensive plant foods is still a very pertinent issue.

Our original division of Agriculture and Chemistry is now divided into three distinct departments: Chemistry, headed by Mr. Guy R. Stewart; Sugar Technology, in charge of Dr. R. S. Norris; and Agriculture, under Mr. J. A. Verret. These, with Entomology, and Botany and Forestry, constitute the five main branches of our work.

The staff comprises thirty men of scientific training, who are aided by about half this number of clerical assistants and laboratory helpers.

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I would call attention to a very important line of work that we have recently taken up, one that should have appeal to all—Forestry.

The watershed forests of Hawaii, so vital to sugar production, are deteriorating rapidly, partly on account of a none too distinct separation of grazing and forest lands, and partly to the changed environment to which the native flora is subjected by the encroachment of introduced grasses.

To remedy this situation the sugar planters have recently extended their coöperation to the Territorial Board of Agriculture and Forestry. We are now formulating ways and means to protect and improve the watersheds that mean so much to the future of Hawaiian agriculture. A branch of this procedure is that of introducing trees and plants from foreign countries, and Dr. Lyon, who heads the work, has already brought together a very rare and valuable collection of plants, some of which will no doubt lend themselves to strengthen our forest cover. There are several hundred thousand acres of forest land to be cared for and the project is one whose fulfillment will take generations.

You see therefore that we are planning ahead. The sugar agriculture of Hawaii is not one of exploiting the primeval fertility of the soil, to be followed by the abandonment of wasted areas; as has been the case with so much of the world's agriculture.

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ON BEHALF OF THE TRUSTEES OF BISHOP MUSEUM

By Albert F. Judd, President of the Board

Mr. Chairman and Gentlemen of the Conference:

It is my pleasant duty as President of the Trustees of the Bernice P. Bishop Museum to join in welcoming to Honolulu the members of the Conference, and to say that for each of you there awaits a cordial greeting at the Museum. We hope that in the laboratory and exhibition halls you will take pleasure in spending your free time as the deliberations of the Conference may permit.

The Museum is a privately endowed institution with a limited income and without governmental or municipal aid. It is governed by a body of seven trustees, all laymen, who account annually to the Court for their stewardship under the deed of trust. The donor of the Trust was Charles Reed Bishop of Glen Falls, New York, who arrived in Honolulu in 1846 and who died in 1915. The Museum is a memorial to his wife, the Princess Bernice Pauahi. Mrs. Bishop, who died in 1884, was the last of the Kamehamehas, the royalty of Hawaii, and as such had inherited a large collection of priceless heirlooms, the feather cloaks, kahilis, calabashes and tapas of her relatives. This and the collection of Queen Emma, the Dowager of Kamehameha IV, are the basis of our ethnological collections. It is extremely probable that the idea of a museum in Honolulu originated with these two royal personages. With rare judgment Mr. Bishop developed the idea, taking counsel with leaders of constructive thought in Hawaii.

The deed of trust provides among other things, for "the maintenance and further equipment and development of the said Bernice P. Bishop Museum as a scientific institution for collecting, preserving, storing and exhibiting specimens of Polynesian and kindred antiquities, ethnology and natural history, and books treating of and pictures illustrating the same, and for the examination, investigation, treatment and study of said specimens, and the publication of pictures thereof and of the results of such investigation and study."

I think you will agree with me that those who framed this deed of trust did their work with vision and farsightedness. Natural history is necessarily interwoven with ethnology and

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in the Pacific region the relation between these two branches of science is particularly close.

The field of our Museum is primarily Hawaii, then Polynesia and the fringe of the Pacific Ocean with its subtle influence on the life of the islands.

I will not attempt to outline the extent of our present collections nor the condition of the library, but will leave you to gain your own impressions at first hand. But let me say this: all suggestions for extensions to or the care of the collections or library will be gratefully welcomed.

Speaking as I do on behalf of a body of laymen to a carefully selected body of scientists, let me say with deliberation that the Trustees realize the size of the task before our Museum.

Because of the Museum's strategic location not only is our opportunity unique but our obligation also is unique. It is our belief that the problems of the Pacific region are too big and too complicated (the men also are too few) and the "vanishing problems" are vanishing too fast to be solved by any one scientific institution, however big and however richly endowed. It is also our belief that the key to these problems is coöperation between existing institutions in the spirit of service to science.

Coöperation with other scientific institutions is no new idea to the Bishop Museum. Possibly the future historian will place us among the leaders of American institutions in this regard, for in 1894 the Trustees were privileged to join with the British Museum, the Royal Society of London and the British Association for the Advancement of Science in the work which culminated in the publication of the "Fauna Hawaiiensis." It is not probable that the work done in Hawaii in economic entomology since 1894 could have been accomplished but for this excursion into pure science.

We believe that coöperation is a relation depending for its success on the attitude of the members thereto (I hope that does not seem too legal) and the attitude of the Trustees and Director and staff is one from which is excluded the idea of competing with other institutions. We believe that in making exchanges of material and books the basis should not be money value, because it is impossible to place a money value on all things. The real basis of exchange should be to support coöperation and advance the cause of science. It is our purpose to send material and books to those institutions that will make

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good use of them, and within the field of our activities we desire to assist in the publication of manuscript which is pigeonholed because no money is forthcoming.

We propose to build up in Honolulu, large Pacific collections not for show nor for pride of ownership, but for study by anybody, and for distribution. It is my personal belief that after it has served the purposes of the investigator, representative material obtained in the Pacific region by expeditions from other institutions, should be deposited in the Bishop Museum. Such a disposition of materials would tend to obviate duplication of effort and funds by making it possible to see what work had already been done.

If this First Pan-Pacific Scientific Conference can state in black and white the unsolved problems concerning the Polynesian race and the Pacific region, and can put into cold type the mature judgment of its members as to the best methods of approaching these problems, there will be written a book which no student of these subjects can disregard, a book for which the Bishop Museum will forever be in your debt.

To sum up, the Bernice P. Bishop Museum is ready to coöperate with others to the limit of its resources within the field marked out by its Deed of Trust.

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